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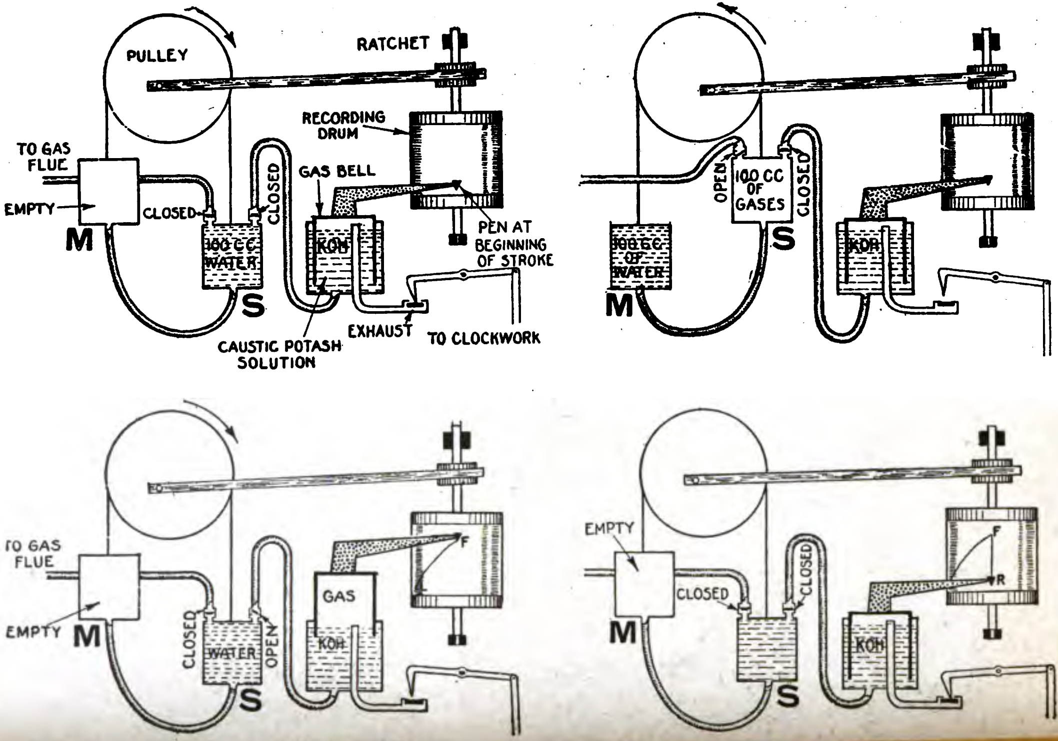

Plate 5.—Elementary CO_2 Recorder.

The operating cycle is here progressively shown; the first figure shows the initial position. **M** and **S.** are the measuring vessles.

AUDELS ENGINEERS AND MECHANICS GUIDE 5

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ENGINEERING PROFESSION

BY

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GRADUATE PRINCETON UNIVERSITY
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NOTE

In planning this helpful series of Educators, it has been the aim of the author and publishers to present step by step a *logical plan of study in* ***General Engineering Practice,*** taking the middle ground in making the information readily available and showing by text, illustration, question and answer, and calculation, the theories, fundamentals and modern applications, including construction *in an* **interesting** *and* **easily understandable** *form.*

Where the question and answer form is used, the plan has been to give *short, simple* and *direct answers*, limited to one paragraph, thus simplifying the more complex matter.

In order to have adequate space for the presentation of the important matter and not to divert the attention of the reader, descriptions of machines have been excluded from the **main text**, being printed in smaller type under the illustrations.

Leonardo Da Vinci once said:

> "Those who give themselves to ready and rapid practice before they have learned the theory, resemble sailors who go to sea in a vessel without a rudder"

—in other words, "*a little knowledge is a dangerous thing.*" Accordingly the author has endeavored to give ***as much information as possible*** in the space allotted to each subject.

> The author is indebted to the various manufacturers for their co-operation in furnishing cuts and information relating to their products.

These books will speak for themselves and will find their place in the great field of Engineering.

Contents of Guide No. 5

CHAPTER PAGES

54. Heat..............................1,755 to 1,778

Definition—the three "states"—***heat unit***—temperature—thermometers and thermometry—absolute temperature—pyrometers—***mechanical equivalent of heat***—expansion and contraction—transfer of heat—conductivity of absorption of heat—specific heat—TABLES.

55. From Ice to Steam...............1,779 to 1,820

Transformation changes—fusion of ice—effect of pressure on melting point—surfusion—work of fusion—contraction and expansion of the liquid—STEAM:—erroneous ideas—formation of steam—latent heat—work of vaporization—sensible heat—internal and external latent heat—external work of vaporization—total heat of saturated steam—boiling point—**How a Boiler Makes Steam**—factors of evaporation—***saving by heating the feed water***—superheated steam—caloimeters and calorimetry.

56. Fuels..............................1,821 to 1,844

Definition—classification—**A.** SOLID FUELS—***coal***—kinds of coal—heating values of coal—sizes—coke—heat—wood—tan bark—straw—sawdust—bagarse—tar—**B.** LIQUID FUELS—comparative evaporation of coal and oil—**C.** GAESOUS' FUEL—natural gas—comparison of gas and coal—tables.

57. Combustion.......................1,845 to 1,886

Combustion explained—carbon—hydrogen—sulphur—ignition—combustion—CO_2—CO—air required—the blow pipe—heating values of fuels—determination of heating value—***ultimate analysis***—available, high, and low heating values—heating values of gaseous fuels—***proximate analysis***—flame—smoke—furnace temperature—ashes—clinker.

58. Fuel Analysis.....................1,887 to 1,918

Why tests should be made—apparatus required—methods — sampling coal—***proximate analysis***—***ultimate analysis***—calormeter test—heating value calculation—ash analysis—analysis of liquid fuels.

59. Flue Gas Analysis................1,919 to 1,938

Waste due to faulty firing—cooling effect of excess air—sampling gases—flue gas collectors—gas pumps—gas analysis—Orsat three and four pipette apparatus—pocket CO_2 indicator.

60. CO_2 Recorders.....................1,939 to 1,954

What CO_2 *indicates*—unreliability of readings—flue gas analyzers *vs*. CO_2 recorders—***how a recorder works***—CO_2 and fuel losses—TABLES.

61. Classification of Boilers...........1,955 to 0,000

Various horizontal ***shell boilers***—various vertical boilers—various ***water tube boilers***—difference between a tube and flue—tubular heating surface—various tube arrangements—various furnace and combustion chamber arrangements—various automobile boilers—difference between a boiler and so-called generator.

62. Characteristics of Boilers.........1,973 to 1,984

Best form of heating surface—function of grate—*grate heating surface ratios*—ratios in common use—gas passages—water space—liberating surface—importance of rapid circulation—steam space—priming—***proper water level***—thin *vs*. thick plates—**Water Tube and Shell Boilers Compared**—quality of the steam with through and submerged tubes—comparison of external and internal furnaces.

63. Boiler Materials...................1,985 to 2,022

1. MATERIALS—copper—brass—brick—cast—malleable and wrought iron—steel—definitions—**2.** PROPERTIES OF MATERIALS— definitions—copper—iron—malleable iron—steel—brick—boiler coverings **3.** TESTS—definitions—**Testing Apparatus**—*calculations*—tension, compression, transverse, shearing, tortional. hardness, cold bending, homogeneity tests—***A.S.M.E. requirements***.

64. Shell Boilers......................2,023 to 2,056

Classes—**1.** EXTERNALLY FIRED—development of the shell boiler—flue—tube—sheets—evolution of the horizontal return tubular boiler—**2.** INTERNALLY FIRED BOILERS—Trevitheck, Lancashire-Galloway boilers—vertical boilers—through and submerged tubes—author's dry pipe—locomotive boilers—marine boilers—difference between Clyde and Scotch types—Western river construction.

65. Water Tube Boilers...............2,057 to 2,098

Classification—arrangement of tubes: *a*, in series; *b*, in parallel—essential parts—early forms—elementary boiler—***circulation principles:*** 1, up flow; 2, down flow; 3, under and over discharge; 4, directed flow—

Water Tube Boilers—*Continued*

non-sectional and sectional boilers—***combustion principles:*** 1, direct and baffled draught; 2, down draught—**Pipe Boilers**—author's home made series pipe boiler—water grate—curved tubes—Talbot contra-flow boiler—Mosher boiler of launch *Norwood*—automobile types—closed tube or porcupine boilers—series parallel tube arrangement—up flow and down flow boilers.

66. **Special Boilers**....................2,099 to 2,126

1. FIRE TUBE BOILERS—duplex and triplex types—horizontal boiler vertically set—vertical extended internal fire box—Manning and Smith types—radial tube—vertical return tube—modified Clyde type—extended shell tri-pas—**2.** COMBINED FLUE AND FIRE TUBE BOILERS—Cornish and Lancashire boilers with fire tubes—**3.** WATER TUBE (OR PIPE) BOILERS—types with special fittings—contra flow—natural baffling—**4.** COMBINED FIRE TUBE (OR FLUE) and WATER TUBE BOILERS—down draught grade—internal firing with large water capacity—single and double row of water tubes—**5.** COMBINED SHELL AND WATER TUBE BOILERS—fire engine boilers—box shell type—**6.** COMBINED SHELL, FIRE AND WATER TUBE BOILERS, with down draught—with Field tubes.

67. **Steam Heating Boilers**...........2,127 to 2,154

Working conditions—heating surface (usually ridiculously small)—effect of inadequate heating surface—rate of combustion—***points of boilers***—division of gases—efficiency of heating surface—short and long pass—fire box proportions—*circulation*—construction details—author's home made pipe boiler—tests—steam dome—automatic control.

68. **Details of Strength and Construction**.................... .2,155 to 2,262

Construction rules (***A.S.M.E.*** and ***Marine***)—boiler plates—shell—strength of shell—bursting pressure—factor of safety—working pressure—thickness of shell—riveted joints—riveted joint calculations —(***A.S.M.E.*** standard for various joints)—***U. S. Marine rules***—heads—tube spacing—area of head to be stayed—riveted socket, and through stays or stay rods—stay tubes—gusset, palm, crow foot, jaw and angle stays—crown or roof bars—radial stays—allowable stresses for stays and stay bolts—boiler opening—steam domes—***properties of boiler tubes***—expanders—fire doors—WATER TUBE BOILER CONSTRUCTION—steam drums—headers and manifolds—***feed water heaters***—***superheaters.***

CHAPTER 54

HEAT

Heat may be defined as *a form of energy in bodies, consisting of molecular vibration*. When heat is applied to a substance, the molecules of which the substance is composed, which are forever moving, ***move faster.*** Again, if the substance be cooled, that is, if some heat be taken away from it, the molecules ***move slower.***

Ques. What is a molecule?

Ans. The smallest particle in which a substance can exist in the free or uncombined state.

It is the least part into which a compound can be subdivided and yet retain its characteristic properties. The molecule of any compound must contain at least two *atoms* and generally consists of many more.

Ques. What are the three "states" of matter?

Ans. Solid, liquid, and gas.

Ques. With respect to the molecules, how are the three states distinguished?

Ans. By the character of their motion.

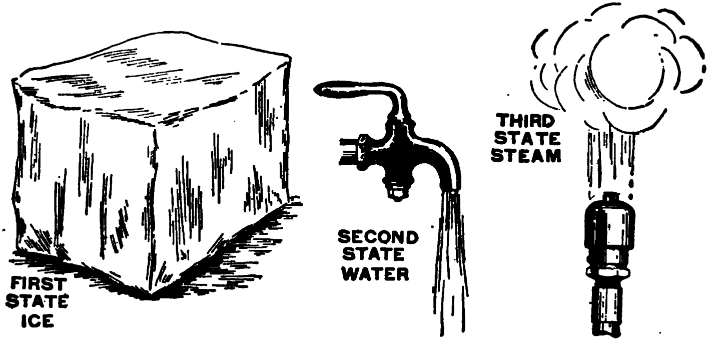
---

*NOTE.—Sir William Thomson estimated that if a drop of water be magnified to the size of the earth, the molecules of water would each be less than the size of a baseball and larger than small shot.

Ques. How do the molecules move in a solid?
Ans. Back and forth like tiny pendulums.

Ques. How do they move in a liquid?
Ans. They wander all around without any definite path.

Ques. How do they move in a gas?
Ans. In straight lines.



FIGS. 3,278 to 3,280.—The three states; solid, liquid, gas, as exemplified by fig. 3,278, a cake of ice; fig. 3,279, water flowing from a faucet, and fig. 3,280 steam escaping from a safety valve. In fig. 3,280 it should be noted that the substance is in the state of a gas only at, or very near the safety valve, or such portion that is invisible.

***The Unit of Heat.**—The present generally accepted heat unit, called the British thermal unit (*B.t.u.*), is defined as $\frac{1}{180}$ *of the heat required to raise the temperature of water from 32° to 212°* Fahr.

---

*NOTE.—The old definition of the heat unit as given by Rankin is: *the quantity of heat required to raise the temperature of 1 pound of water 1° F., at or near its temperature of maximum density (39.1° F)*; this unit was the accepted standard up to 1909. Peabody defines it as *the heat required to raise 1 pound of water from 62° to 63° F, and* Marks and Davis *as* $\frac{1}{180}$ *of the heat required to raise 1 pound of water from 32° to 212° F.* According to Marks and Davis' definition the heat required to raise 1 pound of water from 32° to 212° is 180 instead of 180.3 units, and the latent heat, 970.4 instead of 969.7 units. Evidently this is the mean heat unit and the tendency is toward this as a standard. The heat unit represents a definite *amount* of heat as distinguished from temperature which represents the *intensity* of the heat. Thus the amount of heat so supplied in raising the temperature of 1 pound of water 5° F, or 5 pounds of water 1° F., is 5 heat units. To raise the temperature of 5 pounds of water 5° F., would requires 5 × 5 = 25 heat units, etc.

Temperature.—A substance is said to be *hot* or *cold* according to its physical or sensible effect when touched. This effect depends upon the rate of motion of the molecules, that is to say, the faster the molecules move, the hotter the substance feels, and the slower the motion, the colder the substance. The condition of a substance with respect to its molecular activity is called its *temperature*.

Place the hand in a basin of "cold" water. It feels cold; apply heat to the water, and it gradually becomes warm, that is its temperature is said to *rise*. Again, put a red hot poker into a vessel of water, the poker is "cooled" and the water "heated"; that is, heat passes from the poker to the water, the temperature of the poker is lowered; and that of the water increased. In both cases there has been a *transfer of heat* from one body to the other, the body from which the heat passes is said to have the higher temperature.

Ques. Define the term temperature.

Ans. Temperature is the condition of a body on which its power of communicating heat to, or receiving heat from, other bodies depend.

Ques. When is a body at a higher temperature than another body?

Ans. When its molecules move faster than those of the other body.

Ques. How is temperature measured?

Ans. By a thermometer.

Thermometers.—Experience shows that while an idea of temperature and of the difference between two temperatures may be derived from the sense of touch, no accurate knowledge can be obtained from that source alone.

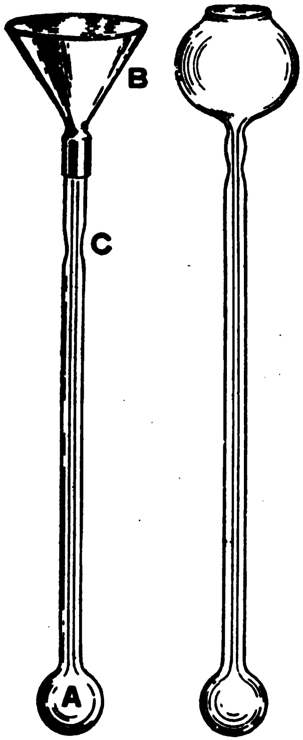
If a piece of metal and a piece of cloth which are lying side by side in front of a fire be touched, the metal will appear hotter than the flannel, though the two may be shown by a suitable experiment to be at the same temperature; again if the two be very cold, the metal will appear the colder. From this must be evident that the sensation does not depend on the temperature alone—it depends also on the *rate* at which heat is transferred to or from the hand and the substance touched. Accordingly it becomes necessary to employ an instrument known as a thermometer to accurately measure temperature.

Ques. Upon what principle are thermometers based?

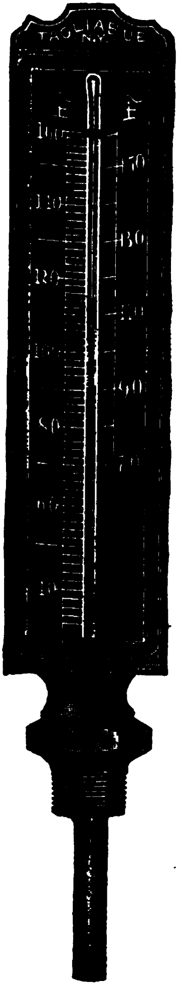
Ans. The expansion and contraction of substances due to the effect of heat.

Ques. What is the substance generally used in thermometers?

Ans. Mercury.



FIGS. 3,281 and 3,282.—Construction of a mercury thermometer. A bulb A, is blown at one end of a glass tube of narrow uniform bore. A cup or funnel B, is formed at the other end. At C, a short distance below the funnel, tube is drawn out by heating it in a blow pipe flame so as to form a narrow neck for sealing off the thermometer when made. If mercury be poured into B, it will not run down the tube to fill the bulb because of the narrowness of the bore. Hence, a small quantity of mercury is placed in B, and the bulb gently heated; the air expands and some of it bubbles out through the mercury in B. The bulb is then allowed to cool and the pressure of the enclosed air falls, thus some of the mercury is forced down the tube, and, if sufficient air has been expelled, into the bulb. When this takes place the mercury in the bulb is boiled, the vapor of mercury forcing most of the air out of the upper part of the bulb and tube. When the bulb is again cooled the mercury vapor condenses and more mercury flows in from the reservoir. By repeating the process once or twice the last traces of air may be removed and the bulb and tube filled with mercury. Now place the bulb and tube in a bath at a rather higher temperature than the highest at which the thermometer is to be used. Some of the mercury expands into the funnel; remove this and allow the thermometer to cool slowly. As the mercury contracts have a blow pipe ready, and as the end of the column is just passing the narrow neck C, heat the tube at that point and draw off the funnel end, thus sealing the tube. The mercury as it cools contracts, leaving a space filled only with mercury vapor.



Ques. Describe the contraction of an ordinary thermometer.

Ans. It consists of a glass tube containing mercury. A bulb is blown on one end of the tube and filled with mercury. When both glass and mercury are heated, the mercury expands more than the glass does, and finds the extra space needed by rising in the fine capillary bore of the stem.

The bore is so fine that a very slight change in the volume of mercury will cause a perceptible change in the length of the thread of mercury in the stem. The cylindrical stem acts as a magnifying glass and makes the thread of mercury look much larger than it is.

Ques. Why is mercury the best liquid for use in a thermometer?

Ans. 1. It remains liquid through a wide range of temperature. 2. Its rate of expansion is nearly constant within ordinary limits. 3. It transmits or receives heat very rapidly, and therefore can be rapidly cooled or heated, and 5, it does not "wet" the glass in which it is contained.

Ques. How is the mercury column made to indicate temperature?

Ans. By means of a scale.

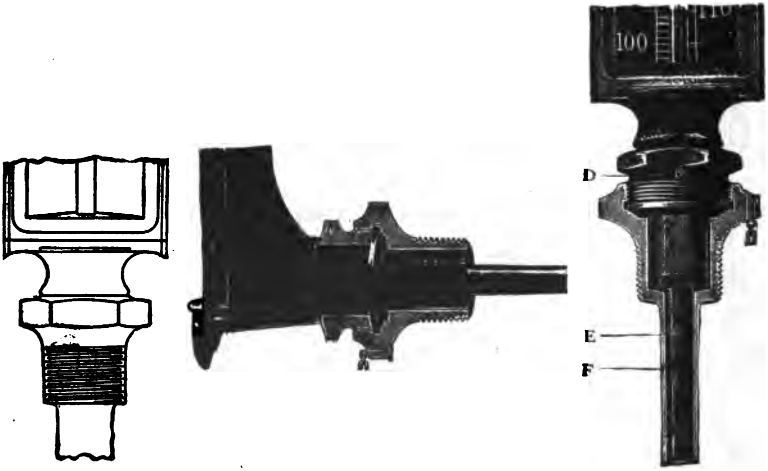
FIG. 3,283.—Tagliabue thermometer for feed water and condenser use; also for injection water. inboard delivery, outboard delivery and other marine uses. Straight form type with fixed thread connection.

Ques. How is the scale graduated?

Ans. By determining the two "fixed points" and then graduating the distance between them into the proper number of degrees corresponding to the particular scale used.

Ques. What are the two fixed points?

Ans. The freezing point and the boiling point.



FIGS. 3,284 to 3,286.—Tagliabue *permanent* thermometer connection. Fig. 3,284 fixed; fig. 3,285, union; fig. 3,286, separable socket. A ***fixed thread*** connection (fig. 3,284) is the simplest form and is recommended for a straight form thermometer only. The ***union*** connection, fig. 3,285, allows regular angle and side form thermometers to be attached in a vertical position without revolving the scale case, and when applied to straight stems, the thermometer face may be turned in any direction. A union connection also relieves the thermometer from all injurious wrenching strains, jars and slips which are likely to occur in attaching. ***A separable socket,*** fig. 3,286, is an additional bulb chamber which exactly fits over the inner bulb chamber of the thermometer, forming a means of connecting the thermometer to an apparatus and, after such connection is made, allowing the thermometer itself to be removed from the socket while the latter remains as a permanent closure of the opening which was made in the apparatus to receive the thermometer. This construction is shown in the sectional illustration at right. D, coupling nut, revolving on thermometer stem; E, tapered bulb chamber; F, socket chamber, with inside taper corresponding exactly to outside of E. Owing to the perfect contact throughout the length of E and F when same are forced together by means of coupling nut D, the temperature is transmitted through the two chambers as readily as if they were one solid piece.

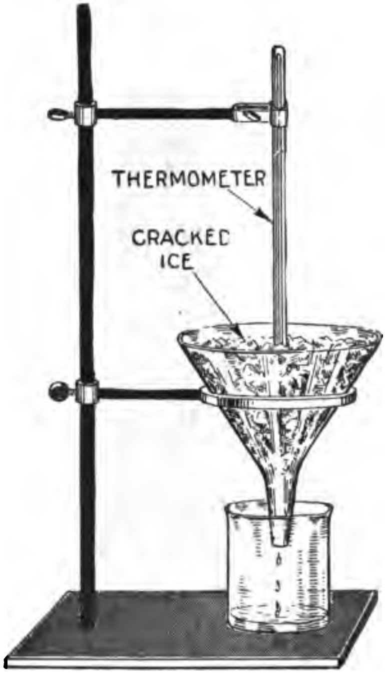
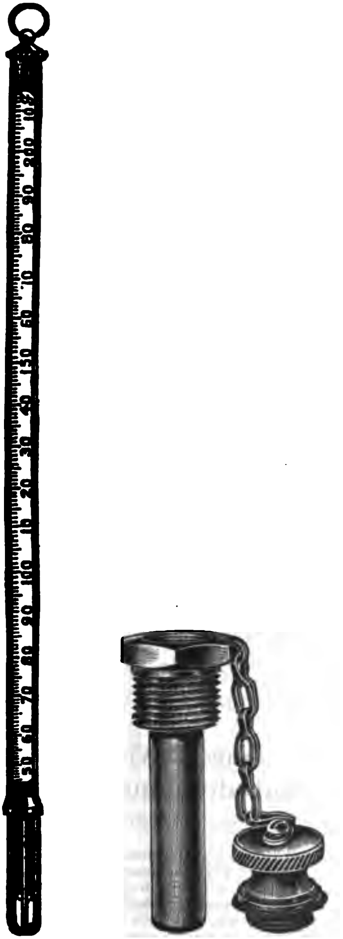
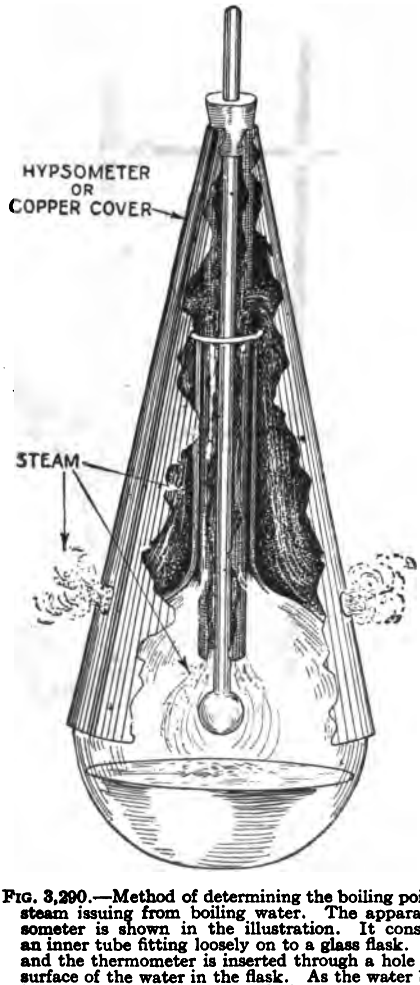


Fig. 3,289.—Method of determining the freezing point Wash some ice, break it small and pack it around the bulb of the thermometer in a glass or metal funnel, so that the water which forms as the ice melts may drain away into a vessel placed below to receive it. The ice should be heaped up around the tube until only the top of the column is visible, and the thermometer left thus covered for 15 minutes. Then, with a fine file, make a scratch on the glass opposite to the top of the column of mercury which represents the freezing point.



Figs. 3,287 and 3,288.—Tagliabue mercury well *temporary* thermometer connection and type of thermometer used with same. The mercury well is designed for use with a solid glass thermometer (fig. 3,287) for test work or for application where only an occasional reading is required. There is a seating plug provided with a gasket for confining the mercury.



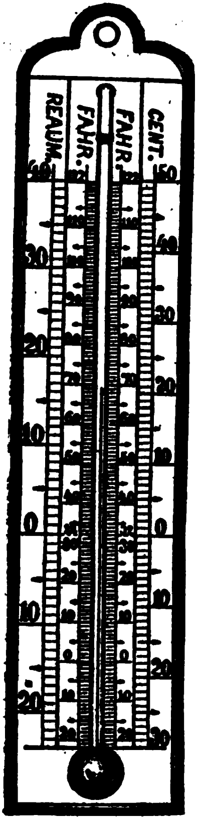
To determine the freezing point, the thermometer is packed in *melting ice* and allowed to remain until the mercury comes to rest, when the height of the liquid is marked on the scale. The thermometer is then immersed in saturated steam at atmospheric pressure, that is, steam formed under pressure of a 30-inch barometer. The mercury will rise a considerable distance, and when it comes to rest its height is located on the stem.

Thermometer Scale.—Since the distance or difference in temperature between the two *fixed points* of a thermometer is considerable, a number of subdivisions should be marked on a scale so that any two temperatures may be more closely compared than would be possible with only the two fixed points.

Ques. What are these sub-divisions called?

Ans. Degrees.

Fig. 3,290.—Method of determining the boiling point. Place the thermometer in the saturated steam issuing from boiling water. The apparatus used for this purpose, called a hypsometer is shown in the illustration. It consists of a conical tin or copper cover, with an inner tube fitting loosely on to a glass flask. A cork passes through the top of the tube and the thermometer is inserted through a hole in the cork, the bulb being well above the surface of the water in the flask. As the water boils steam passes around the thermometer bulb and issues between the flask and the loose cover, flowing down on the outside of the flask between it and the cover. When the mercury ceases to move in the tube adjust thermometer until the mercury level is just visible above the cork, and after leaving it in this position a few moments mark the level of the mercury. Before marking the boiling point read barometer, and if necessary, make correction for standard atmospheric pressure.



Ques. Define a rise of temperature of one degree.

Ans. *It is that rise of temperature which causes the mercury to expand by some definite fraction of the total expansion between the freezing and the boiling points.*

Ques. What are the names of the scales in general use?

Ans. The Fahrenheit, the Centigrade, and the Reaumur scale.

The Fahrenheit thermometer is generally used in English speaking countries, and the Centigrade or Celsius thermometer in countries that use the metric system. In many scientific treatises in English, however, Centigrade readings are also used, either with or without their Fahrenheit equivalents. The Reaumur thermometer is used to some extent on the continent of Europe.

* ***The Fahrenheit Scale.***—The number of degrees between the two fixed points is 180. The freezing point is 32° above zero, hence the boiling point is $32° + 180° = 212°$.

The Centigrade Scale.—The number of degrees between the two fixed points is 100. The freezing point is zero, hence the boiling point is 100°.

FIG. 3,291.—Comparison of thermometer scales, showing relation between values of the Fahrenheit, Centigrade, and Reaumur scales.

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*NOTE.—The first modern thermometer, in which mercury was used, was the invention of Gabriel Daniel Fahrenheit, a German natural philosopher, who died September 16, 1736, at the age of fifty. Fahrenheit was a native of Danzig, and failed as a merchant before he turned his attention to the making of thermometers. At first he used spirits of wine in the tubes, but was dissatisfied with the result, and then used mercury with great success. He opened a shop in Amsterdam, and from there his instruments soon spread throughout the world. The scale suggested by Fahrenheit is still in general use in a large part of the world, although the centigrade thermometer of Celsius, of Stockholm, offered a more rational graduation, and in France Reaumur proposed another graduation, which was adopted in that country. In England and America, however. Fahrenheit is a household word.

The Reaumur Scale.—The number of degrees between the two fixed points is 80. The freezing point is zero, and accordingly, the boiling point, 80°.

Comparison of Thermometer Scales.—It is often desirable to find the equivalent reading of one scale on another scale, because in becoming accustomed to a particular scale, a better conception of temperature is had than for readings on a less familiar scale. Accordingly, the following conversion fraction will be found convenient to obtain equivalent readings.

1 degree Fahrenheit = 5/9 degree Centigrade = 4/9 degree Reaumur
1 " Centigrade = 9/5 " Fahrenheit = 4/5 " "
1 " Reaumur = 9/4 " " = 5/4 " Centigrade

Temperature Fahrenheit = 9/5 × temp. C + 32° = 9/4 R + 32°
" Centigrade = 5/9 × (temp. Fahr. — 32) = 5/4 R
" Reaumur = 4/5 temp. C = 4/9 (Fahr. — 32)

Absolute Temperature.—According to various experiments that have been made with pure gases (with the rise of air thermometers, it has been found that air expands approximately $\frac{1}{459.2}$ of its volume per degree increase in temperature at zero F. $\frac{1}{273.1}$ of its volume at 0° C.) Accordingly, *by cooling the air*

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*NOTE.—***Why Fahrenheit selected 32° as the freezing point.*** Fahrenheit was living in Danzig at the time of his experiments, and knew from many years' experience just how cold it is in that city in the coldest weather. He found that he could exactly reproduce this temperature, anytime, anywhere, by mixing salt with pounded ice. This temperature, he concluded, was the lowest limit of heat, since neither nature out of doors, nor experiments in his laboratory, could go any lower. Accordingly, he put some mercury into a tube and bulb, plunged it into a mixture of salt and ice, and scratched a zero mark on the glass at the top of the mercury column. This he deemed to be the absolute zero. He then calculated the mercury volume at that temperature, and found it to be 1,124 parts. Next he placed the same thermometer in a mixture of ice and water. The mercury promptly expanded and occupied 11,156 parts by volume, or 32 parts of an increase over the zero volume. Accordingly, he scratched the number 32 at this new height of the mercury column, and called it freezing point of water. Next he placed the thermometer in boiling water. The mercury expanded to 11,336 parts or 212 parts higher than zero. This he called the boiling point of water. He divided the scale between 32 and 212 into 180 equal divisions, which he called degrees, and his scale was complete.

below zero, the reverse process should be true; that is to say, for each degree F. decrease in temperature, the volume at zero would be contracted $\frac{1}{459.6}$. It must be evident then, if a volume of a *perfect* gas could be cooled to —459.2° F. it would cease to exist, giving the theoretical point known as the *absolute zero*. However, all gases assume the liquid form at very low temperature, and accordingly do not obey the law of contraction of gases at and near the absolute zero.

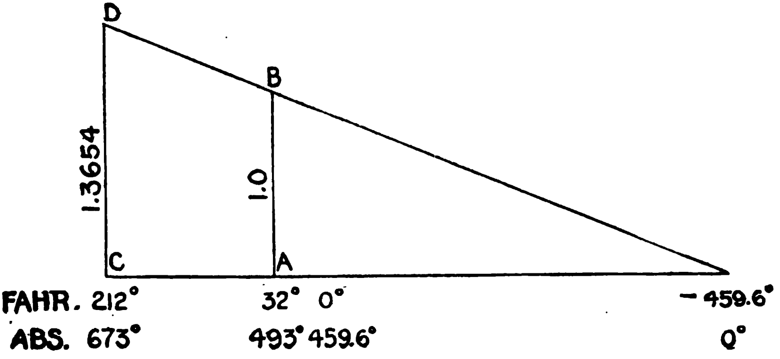


FIG. 3,292.—Graphical method of determining the absolute zero. It is found by experiment that when air is heated or cooled under constant pressure, its volume increases or decreases in such a way that if the volume of the gas at freezing point of water be 1 cu. ft. then its volume when heated to the boiling point of water, will have expanded to 1.3654 cu. ft. Or, inversely, if the volume remain constant, and the pressure exerted by the gas at freezing point = 1 atmosphere, then the pressure at boiling point of water = 1.3654 atmospheres. These results may be set out in the form of a diagram, as here shown. ***In construction,*** draw a horizontal line to represent temperatures to any scale and mark on it points representing the freezing point and boiling point of water, marked 32° and 212° respectively. From 32° set out, at right angles to the line of temperature, a line of pressure AB, = 1 atmosphere to any scale, and at 212° a line CD = 1.3654 atmospheres to the same scale. Join the extremities DB, of these lines to intersect the line of temperatures. It is assumed by physicists that, *since the pressures vary regularly per degree of change of temperature between certain limits within the range of experiment, they vary also at the same rate beyond that range*, and, therefore, that the point of intersection of the straight line DB, produced gives the point at which the pressure is reduced to zero, this point being known as the ***absolute zero.***

The property of air of changing its volume at constant pressure almost exactly in proportion to the absolute temperature, gives a starting point as the basis for all air volume temperature calculations. If P_0 be the pressure and V_0 the volume of a gas at 32° Fahr., = 491.6° on the absolute scale = T_0; P the pressure and V, the volume of the same quantity of gas at any other absolute temperature T, then

$$\frac{PV}{P_0V_0} = \frac{T}{T_0} = \frac{T + 459.2}{491.2}$$

also,

$$\frac{PV}{T} = \frac{P_0V_0}{T_0}$$

The figure 491.2 is the number of degrees that the absolute zero is below the melting point of ice by the air thermometer. On the absolute scale, where division would be indicated by a perfect gas thermometer, the calculated value approximately is 492.66. Thomson considers that —459.4° Fahr. (—273.1° C) is the most probable value of the absolute zero.

Pyrometers.—Mercury thermometers answer all ordinary requirements, but are not adapted to the measurements of high temperatures. For this purpose an instrument known as a pyrometer, of which there are several types, is used. Among the various principles upon which pyrometers are constructed, are:

1. *The contraction of clay by heat.*

As in the Wedgwood Pyrometer used by potters, the method is not accurate because the contraction varies with the quality of the clay.

2. *Expansion of air.*

As in the air thermometer, Weborgh's Pyrometer, Uehling and Steinhart's Pyrometers, etc.

3. *Specific heat of solids.*

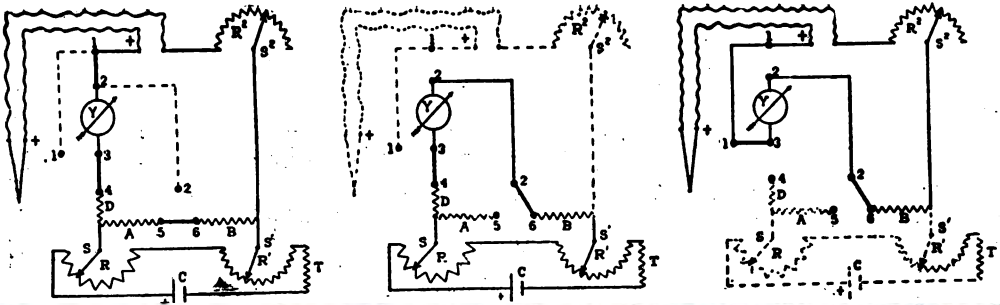
As in the copper ball, platinum ball, and free clay pyrometer.

4. *Relative expansion of two metals or other substances.*

As copper and iron as in Brown's and Buckley's pyrometers, etc.

5. *Melting parts of metal or other substances.*

As in approximate determination of temperature by melting pieces of zinc, lead, etc.



FIGS. 3,293 to 3,295.—Diagrams showing principle and circuits of Brown precision heat meter. This meter is a direct reading temperature indicator in which all errors due to temperature co-efficient or line resistance are eliminated. It has been designed for the measurement of all temperatures within the range of either platinum or base-metal thermo-couples. The Brown Precision Heatmeter may be located near a furnace or connected with a thermo-couple a half-mile distant, and all errors which might occur in ordinary pyrometers through excessive line resistance, are balanced out. It is direct reading, indicating the temperature throughout the whole scale. ***In principle,*** a high resistance millivoltmeter (approximately 600 ohms) is first used as a galvanometer to balance the pressure of the thermo-couple against a pressure from a dry cell, by the null method (position 1, fig. 3,293). Since a balance of reverse pressure is obtained, the measurements are irrespective of line resistance, such as D, R^2 and resistance of the movable coil. The resistor A is of copper. The importance of this feature will be apparent in the second operation. In position No. 2, fig. 3,294, a direct deflection is obtained by means of the dry cell which will be the exact equivalent of the thermo-couple pressure, at the instant they were balanced against each other. When connected as shown, A is cut out, and the copper coil of the galvanometer, having the same resistance as A at the same temperature, is introduced. Therefore, the resistance of D+Y+B will be the same as that of D+A+B in position No. 1. The current which will flow through Y will be the same as in the first operation, and therefore, the pressure at the contactors S and S^1 will be the same as in position No. 1. This is satisfactory as far as it goes, but it will be realized that if a temperature change takes place in the thermo-couple, this will not be indicated, since the thermo-couple is eliminated in position No. 2 and a deflection is obtained by substitution. To obviate this drawback, position No. 3 has been introduced. The purpose of position No. 3, fig. 3,295, is to obtain a direct reading of the thermo-couple, after compensation for errors due to line resistance. This is accomplished by connecting the thermo-couple in series with the movable coil and cutting out the current from the cell. The conditions will again be the same as in figure No. 2, excepting that any change in the line resistance or temperature of the meter will be a factor and will influence the degree of deflection obtained. If the indication in No. 3 differ from that secured in No. 2, the rheostat R^2 is adjusted until they coincide. This condition is easily determined by moving the switch back and forth from position 3 to 2. When the deflection remains the same in both positions the meter can be used in position 3, and will continue to indicate correctly the actual temperature of the thermo-couple regardless of line resistance and the temperature of the meter. Readjustment is only necessary when a possible change in line resistance may have taken place, or a serious change in the temperature of the meter; then by repeating operations 1, 2 and 3 the meter can be checked to overcome such possible sources of error. These operations can be completed in about 10 to 15 seconds. The only possible source of error after operations 1, 2 and 3 have been performed, is a change in the indication of the meter due to spring fatigue, abuse, sticking, etc. This possible source of error can be eliminated by the introduction of a standard cell to check the indications of the meter on the potentiometer principle.

6. *Measurement of strength of a thermo-electric couple.*

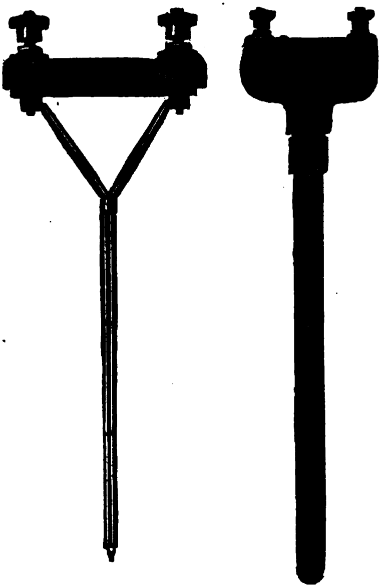
As in Le Chatelier's Pyrometer.

7. *Changes in electric resistance of platinum.*

As in the Sierner's Pyrometer.

8. *Mixture of hot and cold air.*

As in Hobson's hot blast pyrometer.

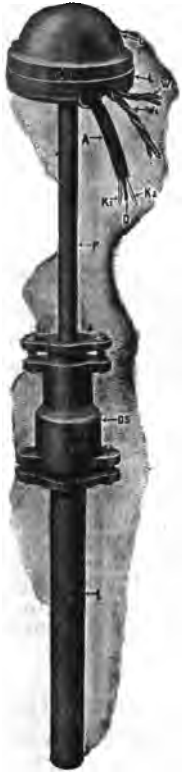


FIGS. 3,296 and 3,297.—Brown platinum rhodium thermo-couples for temperatures up to 3,000° Fahr. The couple is formed of one wire of chemically pure platinum, and the other of 90 per cent platinum and 10 per cent rhodium, the diameter being .02 under, and the melting point of the couple being about 3,150° Fahr. The wires of the thermo-couple are insulated by small porcelain tubes, each pierced with one hole, through which the wires are run. The thermo-couple is protected from the action of gases which tend to destroy platinum by either porcelain or quartz protecting tubes, both of which are impervious to gases, and the thermo-couple has a metal head, fibre cover and brass binding posts. When the thermo-couple is heated it generates a small current of electricity. The current or millivoltage generated by this thermo-couple, if suitable alloys be used, is sufficient to operate an electrical instrument or millivoltmeter. As the temperature of the thermo-couple rises and falls, the thermo-electric current increases or decreases, and is indicated on the instrument, in degrees Fahrenheit or Centigrade, or in millivolts.

9. *Time required to heat a weighted quantity of water enclosed in a vessel.*

As in the water pyrometer.

Ques. Describe a simple pyrometer working on the principle of relative expansion of two substances.



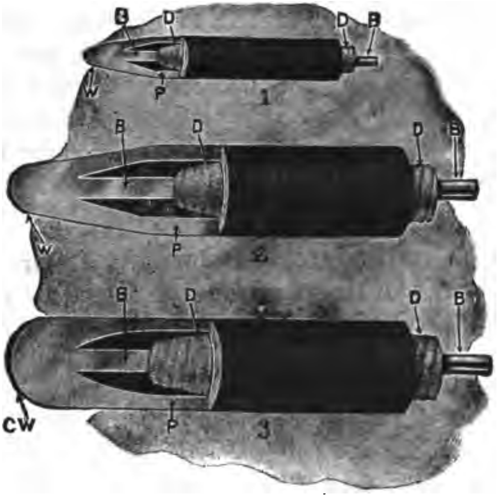


FIG. 3,298.—Foxboro "pyod" or base metal thermo-couple, one element of which is a tube the other element being a wire on which is wound pure asbestos insulation. The two elements are welded into a junction at one end—the hot end—as shown at the tips of the sections of the three couples. Pyods are intended for use under continuous service up to 1,650° or for intermittent service up to 1,800° Fahr. ***The parts are,*** C,L, zone box No. 4; W, copper leads; A, auxiliary couple; P, pyod; DS, double stuffing box; I, iron or iralume protection pipe.

FIGS. 3,299 to 3,301.—Sectional views of Foxboro "pyod" junctions showing construction. B, center wire element; D, asbestos insulation; tubular element; W, weld; CW, cup weld for special use.

NOTE.—Metallic pyrometers used for determining high temperatures must be handled cautiously owing to the difficulty of exposing the whole of the stem to the current of gas, the temperature of which is to be determined. Electric pyrometers either of the thermo-couple or resistance type are satisfactory for this work within their practical limit, which is 1,800° Fahr. for iron-nickel couples and 3,000° Fahr. for platinum-radium couples or platinum resistance pyrometers. Instruments of this kind can readily be calibrated by comparing them at low ranges of temperature with a standardized mercurial thermometer, both being placed for example in a current of hot air the temperature of which is under control. For extremely high temperatures such as that of a boiler furnace, optical, pneumatic and radiation pyrometers may be used. The calibration of high-temperature instruments can best be undertaken in a laboratory especially fitted for the purpose.

Ans. A pyrometer of this type may be constructed by enclosing a rod of graphite in a tube of iron. The graphite expands and contracts more than iron, behaving just as the mercury and glass in a mercury thermometer. There is a limit to the use of this pyrometer as the very high temperatures met with in furnace work will melt the iron and boil the carbon. Carbon has the curious property of boiling before it reaches its melting point.

High Temperature Judged by Color.—The temperature of a body can be approximately judged by the experienced eye unaided, and M. Pouillet has constructed a table, which has been generally accepted, giving the colors and their corresponding temperature as below:

	Deg. C	Deg. F
Incipient red heat..	525	977
Dull red heat......	700	1,292
Incipient cherry red heat.............	800	1,472
Cherry red heat....	900	1,652
Clear cherry red heat	1,000	1,832
Deep orange heat..	1,100	2,021
Clear orange heat..	1,200	2,192
White heat.......	1,300	2,372
Bright white heat..	1,400	2,552
Dazzling white heat	1,500 to 1,600	2,732 to 2,912

According to Kent, the results obtained, however, are unsatisfactory, as much depends on the susceptibility of the retina of the observer to light as well as the degree of illumination under which the observation is made.

The Mechanical Equivalent of Heat.—Almost everyone knows that hammering a nail will make it hot, or that the barrel of a bicycle or automobile pump will become heated in pumping up a tire, but comparatively few know that there is a direct numerical relationship existing between the amount of work done and the quantity of heat produced. This relationship is known as the "*mechanical equivalent of heat,*" and was discovered by Dr. Joule of Manchester, England, in 1843.

Joule reasoned that if the heat produced by friction, etc., be merely mechanical energy which has been transferred to the molecules of the heated body, then the same number of heat units must always be produced by the disappearance of a given amount of mechanical energy. And this must be true no matter whether the work be expended in overcoming the friction of wood on wood, of iron on iron, in percussion, in compression, or in any other conceivable way. To see whether or not this were so, he caused mechanical energy to disappear in as many ways as possible, and measured in every case the amount of heat developed.

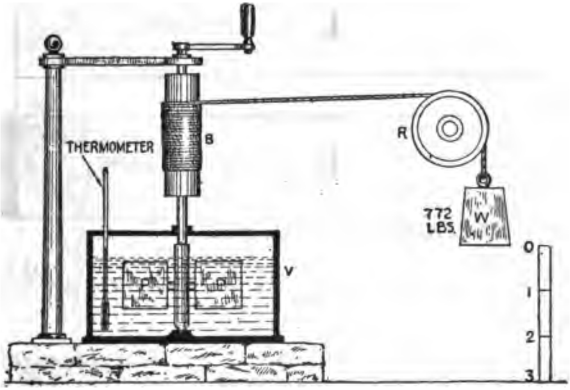
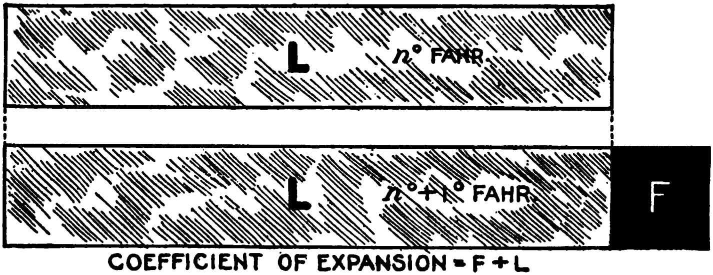


FIG. 3,302.—The mechanical equivalent of heat. In 1843 Dr. Joule of Manchester, England, performed his classic experiment, which revealed to the world the mechanical equivalent of heat. As shown in the figure, a paddle was made to revolve with as little friction as possible in a vessel containing a pound of water whose temperature was known. The paddle was actuated by a known weight falling through a known distance. ***A pound falling through a distance of one foot represents a foot pound of work.*** At the beginning of the experiment a thermometer was placed in the water, and the temperature noted. The paddle was made to revolve by the falling weight. When 772 foot pounds of energy had been expended on the pound of water, the temperature of the latter had risen one degree and the relationship between heat and mechanical work was found; the value 772 foot pounds is known as Joule's equivalent. More recent experiments give higher figures, the value 778, is now generally used but according to Kent 777.62 is probably more nearly correct. Marks and Davis in their steam tables have used the figure 777.52.

Expansion Due to Heat.—One effect of heat is to cause substances to expand. This may be explained by saying that heat is molecular motion. An increase of heat is due to an increase in the velocity of motion of the molecules. Accordingly the molecules by their more frequent violent collisions become separated a little farther from one another, and as a result the body expands, as shown in the experiments illustrated in the accompanying cuts. The amount by which, say a rod of metal increases in length for a moderate use of temperature differs for different metals, but is in all cases very small. Experiments show that the increase in length is proportional to the original length and to the change of temperature, careful experiments have been made to find for each substance a factor called the coefficient of expansion.



FIGS. 3,303 and 3,304.—Coefficient of expansion. If a bar of length L, at temperature *n*° Fahr., as in fig. 3,303, be heated to n° + 1° Fahr., and expand a distance F, as in fig. 3,304, then the coefficient of expansion is F ÷ L.

Ques. Define the coefficient of linear expansion?

Ans. It is *the ratio of the increase in length produced by a rise of temperature of 1° to the original length.*

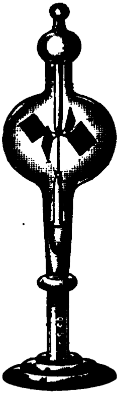
Ques. What provision must be made on boilers because of the expansion of the metal due to heat?

Ans. In setting horizontal shell boilers, one end is supported on rollers to allow expansion and contraction with temperature changes; the tubes of water tube boilers are arranged so they are free to expand and contract; steam mains, especially when long have expansion joints, or the equivalent.

A better method of providing for expansion in boiler shells is to suspend them by links attached to overhead cross beams.

Ques. State some advantages and disadvantages of expansion and contraction due to heat.

Ans. Boiler plates are fastened with red hot rivets. When the rivets cool they contract and bind the plates together with great force. Iron tires are first heated and then put onto the wheel. When the iron cools, the tire contracts and binds the wheel. A short space must be left between the rails of a railroad to permit expansion and contraction without injury.



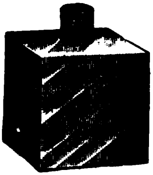


FIG. 3,305.—Radiometer. It consists of a partially exhausted bulb within which is a little aluminum wheel carrying four vanes blackened on one face and polished on the other. When the instrument is held in sunlight or before a lamp the vanes rotate in such a way that the blackened faces always move away from the source of radiation. This is because the blackened faces absorb ether waves better than do the polished faces, and thus become hotter. The heated air in contact with these faces then exerts a greater pressure against them than does the air in contact with the polished faces. The more intense the radiation, the faster is the rotation.

FIG. 3,306.—Leslie's cube for illustrating lines of radiation. It has four polished faces.

Transfer of Heat.—There are three ways in which heat may be transferred from one body to another at lower temperature, as by:

1. Radiation.
2. Conduction.
3. Convection.

These three methods of transfer are clearly illustrated in the operation of a steam boiler, thus heat from the burning fuel passes to the metal of the heating surface by *radiation;* it passes through the metal by *conduction,* and is transferred to the water by *convection.*

When heat is transmitted by radiation, the hot body, as the burning fuel in the above example, *sets up waves in the ether.* When the waves fall upon another body (as the boiler plate) its energy is again converted into heat. The waves are not heat, *but are caused by heat and may cause heat.*

In conduction, heat travels through a body (as the boiler plate) from molecule to molecule. At points where the temperature is high the molecules are moving faster than at points where the temperature is low. The molecules communicate the motion to the adjacent molecules, they to others, and in this way heat passes through the body.

Water and most other liquids are very poor conductors of heat, that is, heat is not readily transferred to them by conduction. Hence, if an upright test tube be filled with water and a flame be applied to its upper portion, the water will boil vigorously at the top while no perceptible heat is felt at the bottom.

Now if the heat be applied at the lowest point, all of the water is quickly raised to the boiling point. The explanation is that the water next to the bottom is first heated and caused to expand. Then it rises because of the buoyant effect of the denser cold liquid. In this way *convection currents* are set up which continually raise the warmer water to the top and permit the cooler water to sink to the bottom. The movement of the water thus set up is called *circulation* in boilers, and the successful operation of any boiler depends upon a proper circulation, so that the heat may be rapidly transferred to the water by convection.

Conductivity.—On a cold day a piece of metal feels much colder to the hand than a piece of wood, notwithstanding the fact that the temperature of the wood must be the same as that of the metal. On the other hand, if the same two bodies had been lying in the hot sun in midsummer, the wood might be handled without discomfort, but the metal would be uncomfortably hot. The explanation of this phenomena is found in the fact that the iron, being a much better conductor than the wood, imparts heat to the hand much more rapidly in summer, and removes heat from the hand much more rapidly in winter, than does the wood. In general, the better the conductor, the hotter it will feel to a hand colder than itself, and the colder to a hand hotter than itself.

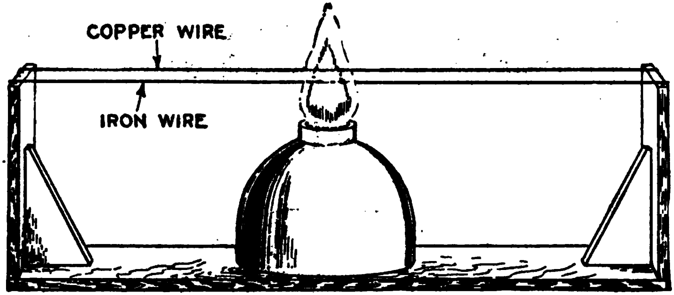


Fig. 3,307.—Experiment illustrating the difference in conductivity of metals. Take two wires, say copper and iron, and stretch them across a flame as shown. Rub the wires back and forth with a piece of beeswax and at the same time hold a flame beneath the wax. Numerous beads of the wax will cling to the wires. When cool, let a flame play against the wires at one point. The wax will melt and flow much farther from the flame on the copper than on the iron wire. At the point where the flame is applied, the iron will become red-hot before the copper does, because the heat cannot so readily leave that point on the iron and also because the capacity of iron for heat is less than that of copper.

All metals are good conductors, though some are much better than others, silver and copper being the best Any substance that is a good conductor of electricity is also a good conductor of heat.

Most ordinary liquids and all gases are poor conductors. The experiment in fig. 3,307 illustrates the difference in conductivity of metals.

The relative conductivity of a number of important substances is given in the table below:

Silver	1.096	Marble	.005
Copper	1.041	Glass	.0025
Aluminum	.344	Water	.0014
Zinc	.303	Cork	.0007
Iron	.167	Hydrogen	0004
Mercury	.0152	Air	.000056

Absorption of Heat.—Some substances readily absorb the heat waves which fall upon them. Thus, if a thermometer bulb be covered with soot or lamp black, it will show a higher temperature than one near by which is not so heated.

Polished surfaces are poor absorbers and also poor radiators, while rough surfaces are both good absorbers and radiators. The radiometer, shown in fig. 3,305, illustrates the absorption of heat.

Specific Heat.—By experiment upon different substances it has been determined that it requires different amounts of heat to change their temperatures one degree. Water is taken as the standard for specific heat; that is, the specific heat of any substance is expressed in terms of the amount of heat required to raise the temperature of water one degree; thus, by definition, the specific heat of a substance is *the ratio of the quantity of heat needed to raise its temperature one degree to the amount needed*

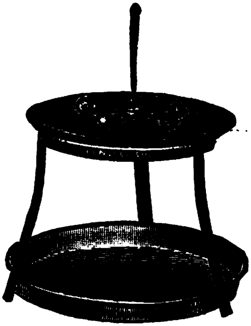


FIG. 3,308.—Tyndall's specific heat apparatus. *It consists of* a metal plate, paraffine cake, tripod support and five balls of different metals with holder. *In experiment,* the balls are supported on the holder and heated in boiling water. Then, when placed on the paraffine cake, they will melt their way through it at different rates, depending on their specific heats. The metal plate is used as a mould to form the paraffine cake and also to catch the balls on their fall.

to raise the temperature of the same weight of water one degree; expressed as a formula,

$$\text{Specific heat} = \frac{B.t.u.\ \text{required to raise temperature of substance } 1^\circ}{B.t.u.\ \text{required to raise temperature same weight water } 1^\circ}$$

from this it follows that,

Specific heat = B.t.u. required to heat one lb. of a substance 1°F.

One of the simplest methods of determining specific heat is by mixing the substance with water.

Example. Suppose that six pounds of mercury at 100° C, be poured into two pounds of water at 0° C, and that the resulting temperature of the "mixture" is 9°. The specific heat S, of the mercury can then be found as follows:

In falling from 100° to 9° the six pounds of mercury give out 6 × (100—9) × S, or 546 S heat units. These have gone to heat two pounds of water from 0° to 9°, which requires 2 × 9, or 18 heat units. Hence, we may write,

$$546\ S = 18$$

Therefore,

$$S = 18 \div 546 = .033$$

As given by Röntgen, the specific heat of various substances are as follows:

Specific Heat of Various Substances

Solids

Copper		.0951
Wrought iron		.1138
Glass		.1937
Cast iron		.1298
Lead		.0314
Tin		.0562
Steel	Soft	.1165
	Hard	.1175
Brass		.0939
Ice		.504

Liquids

Water	1.
Sulphuric Acid	.335
Mercury	.0333
Alcohol (nnn)	.7
Benzine	.95
Ether	.5034

Gases

	Constant pressure	Constant volume
Air	.23751	.16847
Oxygen	.21751	.15507
Hydrogen	3.409	2.41226
Nitrogen	.438	.17273
Ammonia	.08	.299
Alcohol	.4534	.399

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*NOTE.—***Specific heat of gases.*** Experiments by Mallard and Le Chatelier indicate a continuous increase in the specific heat at constant volume of steam, carbon dioxide, and even the perfect gases, with rise of temperature. The variation is inappreciable at 212° F., but increases rapidly at the high temperatures of the gas engine cylinder.

CHAPTER 55

FROM ICE TO STEAM

In the transformation of a pound of ice into a pound of steam, by the application of heat, several changes take place, and a considerable amount of work is done in effecting these changes. The process may be divided into several stages:

1. Fusion of the ice;
2. Contraction of the water;
3. Expansion of the water;
4. Evaporation of the water.

During this series of changes **the substance has existed in three *states,*** that is,

1. As a solid.
2. As a liquid.
3. As a gas.

Ques. What is a solid?

Ans. A form of matter in which the molecules lie close together with little freedom of movement, and in which they cannot be separated, except by the application of a definite amount of force.

Maxwell defines a solid as a body which can sustain a longitudinal pressure without being supported by a lateral pressure.

Ques. What is a liquid?

Ans. A body whose molecules move easily among themselves and yield to the least force impressed.

All liquids are fluids, but not all fluids are liquids. Air and all gases are fluids, but they are not liquids under ordinary circumstances, though capable of being reduced to a liquid form by cold and pressure. Water at ordinary temperatures is a liquid.

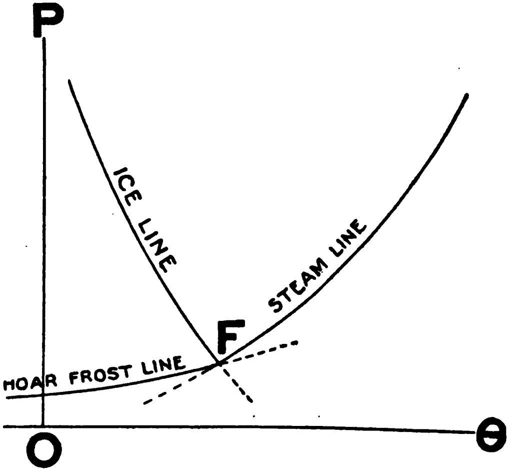

FIG. 3,309.—Diagram illustrating the ***triple point***, or *that point in which a substance can exist in all three states (solid, liquid, gas) in equilibrium.* For example, there is a certain temperature and pressure at which water substance may exist partly as ice, partly as water, and partly as vapor, so that the lower part of a closed vessel containing the mixture will be filled with water in which ice floats, while the upper part is filled with saturated vapor, the pressure within the vessel being that of the water vapor at the temperature of the mixture. The curve of maximum vapor pressure is called the *steam line*. When the ice and water are in stable equilibrium, the temperature of the mixture is that at which the solid melts under the pressure within the containing vessel. This pressure is also completely determined by the temperature, and the relation connecting this may be represented graphically by a curve called the *ice line*. A third curve called the *hoar-frost line** shows graphically the relation between temperature and pressure of a substance when existing partly in the solid state and partly in the condition of vapor. Evidently a substance under the condition of temperature and pressure as indicated by **F**, the point of intersection of the three curves, or the ***triple point***, can exist in all the three states, that is, as a solid, liquid, and gas.

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*NOTE.—Regnault concluded that in passing from the vapor of the liquid to that of the solid there is no appreciable change in the vapor pressure curve and that consequently the hoar-frost line is simply a continuation of the steam line. It was later shown by Kerchoff that the steam line and hoar-frost line are not continuous, but are distinct curves, intersecting each other at an angle as shown in the figure.

Ques. What is a gas?

Ans. A fluid which is elastic and which tends to expand indefinitely.

A gas is in nearly all cases under ordinary conditions characterized by great transparency and such extreme tenuity as to be imperceptible to touch when at rest.

Fusion of Ice.—In order to transform a pound of ice into steam, it must pass through two changes of state, that is to say, 1, from a solid to a liquid, and 2, from a liquid to a gas. Heat is required to effect each of these changes, being known as latent heat, and called respectively:

1. Latent heat of fusion.
2. Latent heat of evaporation.

Ques. What is understood by the term "change of state"?

Ans. A substance undergoes a "change of state" when it changes from a solid to a liquid, or from a liquid to a gas.

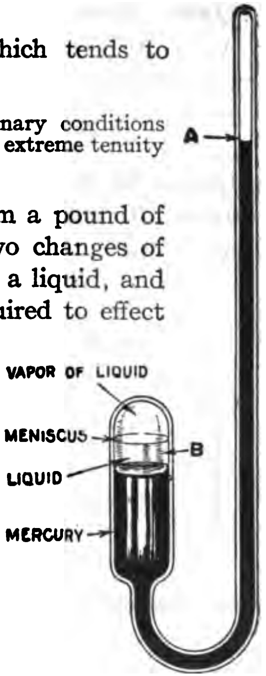


FIG. 3,310.—Cagniard de La Tour's experiment illustrating *critical temperature*. By definition the critical temperature is *that temperature to which a gas must be cooled before it can be converted into a liquid by pressure*, that is to say, there is a temperature for all gases such that the substance can be liquified by pressure only if it be below this temperature which is known as the critical *temperature*. As shown, the apparatus consists of a bent tube, one end A, containing air to indicate pressure, and the other end B, the liquid to be experimented upon. The space between A and B, is filled with mercury. If both arms be graduated the critical pressure and volume may be determined simultaneously. At low temperatures the vapor pressure may be less than that caused by the air in A, and the column of mercury. As the temperature of B, is raised the vapor pressure increases, and the mercury is forced into the other arm compressing the air to some point A. Since the pressure supported by the liquid at any temperature is that of the saturated vapor at that temperature, the formation of bubbles below the surface (boiling) is impossible. Accordingly evaporation proceeds without boiling till the temperature rises to a certain point, at which a very striking transformation occurs. The *menescus* or surface separating the liquid and vapor grows indistinct and completely disappears, and the substance appears no longer; to exist in two states. That is, the whole space above the mercury in B, now appears to be filled with vapor only. On cooling down again a mist suddenly appears about the middle of the apparently empty space and spreads rapidly throughout the whole interior and suddenly vanishes, leaving the lower part of the tube filled with liquid. The critical temperature of water is 689° Fahr.; ammonia, 266°; carbon dioxide, 88°; air, —220°; oxygen, —182°; hydrogen, —389°.

Ques. How is a change of state effected?

Ans. By a transfer of heat to or from the substances, according as the change of state is from a solid to a liquid or gas, or from a gas to a liquid or solid, respectively.

Ques. Is the temperature of the substance raised or lowered during a change of state?

Ans. No.

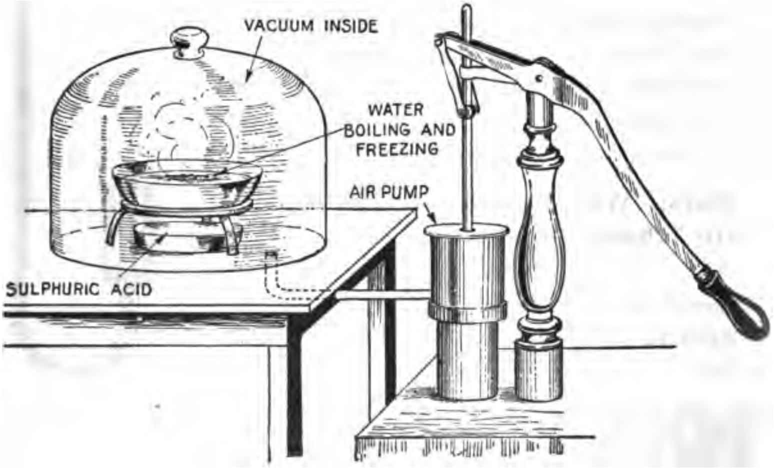


Fig. 3,311.—Leslie's experiment showing water freezing as it boils. A small pan containing some water is placed over a dish filled with sulphuric acid, and the air removed with an air pump. On removal of the air the water evaporates rapidly and begins to boil, being greatly facilitated by the sulphuric acid which absorbs the vapor almost as rapidly as formed. The temperature of the water is quickly reduced and it finally solidifies, thus the liquid is frozen while in the act of boiling.

Ques. What is fusion?

Ans. The term "fusion" signifies the change of state of a substance from the solid form to the liquid form. This is popularly known as melting.

Ques. Describe the fusion of one pound of ice.

Ans. If heat be applied to the ice it will gradually melt, but during the melting process the temperature will remain unchanged.

Ques. What is the heat called which is required to melt the ice?

Ans. The latent heat of fusion.

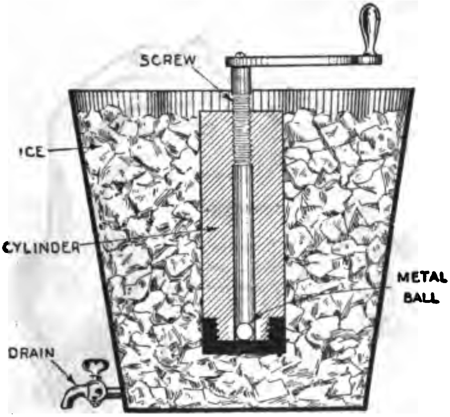


FIG. 3,312—Experiment illustrating the effect of pressure on the melting point. A very strong cylinder fitted with a screw at one end is filled with water and the latter frozen. A metal ball is placed on top and the cylinder closed by water. The cylinder is then covered with ice and pressure applied by the screw. The effect of the pressure is to lower the freezing point causing the ice to melt within the cylinder, thus permitting the ball to drop to the bottom. On opening the cylinder, thus reducing the pressure within, the water again freezes, this re-freezing being known as *regelation*. By removing the lower cap the ball is found at the bottom of the cylinder.

The latent heat of fusion may be defined as the heat required in *B. t. u.* to convert one pound of a substance from the solid to the liquid state without change of temperature.

Ques. How much heat is required to melt one pound of ice at 32°?

Ans. 143.57 heat units.

Professor Wood considers 144 heat units (*B.t.u.*) as the most reliable value for the latent heat of fusion of ice. Pearson gives 142.65. The United States Bureau of Standards (1915) gives it as 143.57 *B.t.u.*

Ques. What name is given to the temperature at which fusion takes place?

Ans. The melting point.

Ques. Upon what does the melting point depend?

Ans. Upon the pressure.

Fig. 3,313.—Familiar operation of making a snowball illustrating *regelation*. When the snow is packed together with the hands, the pressure thus applied *lowers the freezing point* and some of the snow melts. On removing the pressure the water formed re-freezes, that is regelation takes place and the ice firmly binds together the "ball." When the snow is too cold it will not bind unless very heavy pressure be applied.

Ice melts at 32° F. at ordinary atmospheric pressure, and water freezes at the same temperature. At higher pressures the melting point of ice, or the freezing point of water, is lower, being at the rate of .0133° F. for each additional atmosphere of pressure.

The lowering of the freezing point of water by pressure or, as it may be put, the melting of ice under pressure explains many phenomena which would otherwise be very puzzling. The melting of ice under pressure, and re-solidification when the pressure is removed, presents itself in many ordinary occurrences, for instance, the wheel track of a heavy cart in snow is generally sheeted with a plate of clear ice. The snow, if not too cold, melts, or partially melts under pressure of the wheel and solidifies again into transparent ice as soon as the pressure is removed.

The same process takes place in the making of a snowball. If the snow be near the melting point, the pressure of the hand is sufficient to squeeze it into a compact partially solidified mass. When the snow is squeezed between the hands, melting occurs at the points of greatest pressure, and solidification follows as soon as the resulting liquid is relieved of the pressure.

If the snow be much below the freezing point, however, the pressure of the hand will not be sufficiently great, and the ball will not "make."

Surfusion.—Some liquids are in an unstable condition at the freezing point; that is, a liquid which crystallizes in solidifying, may be carefully and slowly cooled, be reduced to a temperature much below the freezing point, without solidification taking place.

If the over cooled liquid be disturbed, or a small piece of the crystalized solid be placed in contact with it, solidification at once sets in and continues until the temperature rises to the normal freezing point. This peculiar behavior which was discovered by Fahrenheit in 1724, is called "*surfusion;*" he found that a glass bulb filled with water and hermetically sealed, remained at a temperature considerably below the freezing point without solidification taking place, but that on breaking off the stem, solidification rapidly set in.

Ques. What important change takes place during the melting of ice?

Ans. It decreases in volume.

The relative volume of ice to water at 32° F. is as 1.0855 to 1; that is, the space occupied by one pound of ice is 8.55 per cent. greater than that occupied by one pound of water at the same temperature. Specific gravity of ice = .922, water at 62° F. being 1.

Ques. Why is this change of volume important?

Ans. Because of the precautions which must be taken with apparatus in which water is used, to prevent damage in case of freezing when not in use.

When water freezes, the increase in volume will take place against almost any force however great, as exemplified in the bursting of exposed water pipes in cold weather. Thus, water pipes burst when the temperature is a few degrees below 32°, although it requires a pressure of about 14,000 pounds per square inch to burst an ordinary pipe.

The Work of Fusion.—In order to change the state of a substance work must be done, that is to say, a transfer of heat must take place. As already stated, it requires 143.6 heat units to melt one pound of ice "from and at 32° F." One heat unit has been found by experiments to be equivalent to 777.5 foot pounds of energy, and accordingly the work done during the fusion of the ice is

$$777.5 \times 143.6 = 111{,}649 \text{ ft. lbs.}$$

that is to say, 111,649 foot pounds is expended in melting one pound of ice from and at 32° F. This expenditure of energy consists of

1. The internal work of fusion;
2. The external work of fusion.

The internal work represents the energy expended in changing the crystalline structure of the solid to that corresponding to the liquid state, and in amount is equal to the total work of fusion minus the external work; that is,

internal work = total work — external work

The external work is the work done by the atmosphere during the change of volume which takes place during fusion. It is calculated as follows: 1 cubic foot of water at 32° F. weighs 32.42 pounds, hence the volume of 1 pound of water at the same temperature = 1,728 ÷ 62.42 = 27.68 cubic inches. Now the volume occupied by 1 pound of ice at 32° F. is as

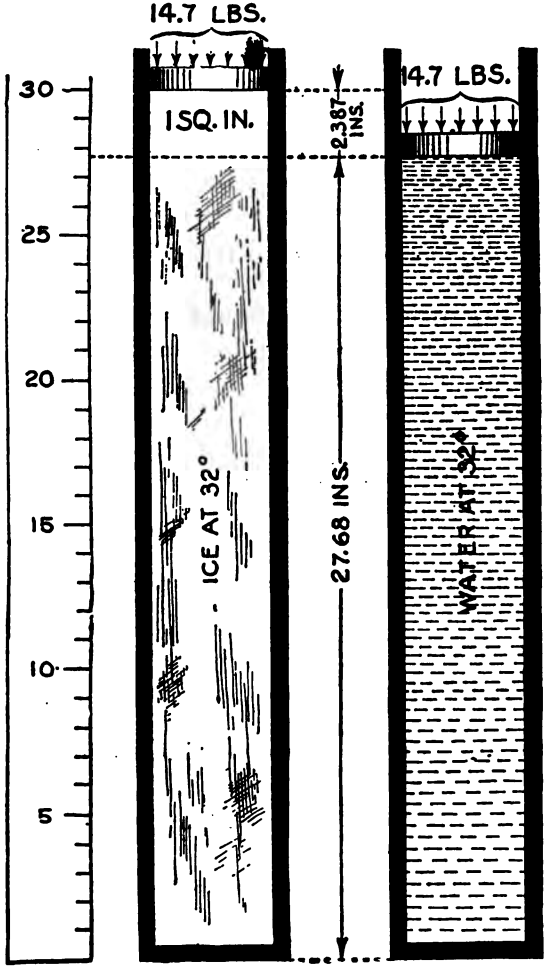


FIG. 3,314.—***The external work of fusion.*** The volume of 1 pound of ice at 32° Fahr. is 30.067 cu. ins., and 1 pound of water at 32°, 27.68 cu. in. Hence, if placed in a long cylinder whose cross sectional area is 1 sq. in., the ice and water will fill the cylinder to height of 30.067 and 27.68 ins., respectively. Now the pressure of the air pressing down on the ice and water is 14.7 pounds, as represented by the piston and arrows. Hence, during fusion of the ice the external work done by the atmosphere is:

$$\frac{(30.067-27.68)}{12} \times 14.7 = 2.92 \text{ ft. lb}$$

given in fig. 3,314 30.067 cubic inches, and the difference in volume is 30.067 — 27.68 = 2.387 cubic inches; that is, assuming the ice to be of a cube 1 square inch in cross section and 30.067 inches long, its length decreases 2.387 inches during fusion, and the pressure of the atmosphere (14.7 pounds per square inch) has acted through the distance, accordingly the work done by the atmosphere, or the external work of fusion = (2.387 ÷ 12) × 14.7 = 2.92 foot pounds.

The internal work = total work — external work = 111,649 — 2.92 = 111,646.08 foot pounds.

Summary—Fusion of one pound of ice from and at 32° F.
Total work of fusion = 777.5 × 143.6 = 111,649 ft. lbs.
External work of fusion = (2.387 ÷ 12) 14.7 = 2.92 ft. lbs.
Internal work of fusion = 111,646 — 2.92 = 111,649.08 ft. lbs.

Contraction and Expansion of the Liquid.—If additional heat be applied to the pound of ice which has just been transformed into water at 32° F. its volume will contract until the temperature has been raised to 39.1° F.

Ques. What is this point called?

Ans. The point of *maximum density.*

Ques. What should be noted about this point?

Ans. Water at its point of maximum density (39.1° F.) will expand as heat is added, and it will also expand slightly as the temperature falls from this point.

Ques. How does the water behave on increasing its temperature above 39.1°?

Ans. It expands as its temperature is raised.

Ques. What is the point of least density?

Ans. The temperature at which steam begins to form.

---

*NOTE.—These figures show that the external work of fusion is extremely small as compared with the internal work. It should be remembered that in fusion the external work represents an amount of work *done by the atmosphere on the substance undergoing a change of state*, and should be noted that this is just the opposite to what happens in evaporation, in which case, the external work of evaporation, as will be shown later, represents an amount of work *done by the substance undergoing a change of state upon the atmosphere.*

STEAM

The average person has a very vague idea of the meaning of the word *steam.* It may be defined as the *vapor of water;* the hot invisible vapor given off by water at its boiling point. *The visible white cloud popularly known as steam is not steam, but a collection of fine watery particles, formed by the condensation of steam.*

It is important that those who install, or have charge of boilers, should have some knowledge of the nature of steam, its formation and behavior under various conditions. This knowledge should be possessed not only that the plant may be intelligently installed and properly operated, but the person thus engaged should be sufficiently interested in his occupation that he be desirous of knowing all about the important medium he has to deal with.

There are several kinds of steam:

1. Wet steam.
2. Saturated or dry steam.
3. Superheated steam, sometimes called gaseous or steam gas.

Ques. What is wet steam?

Ans. Steam of a temperature corresponding to its pressure and having intermingled mist or spray.

Ques. What is saturated steam?

Ans. *Steam having a temperature corresponding to its pressure.*

Ques. What is dry steam?

Ans. Saturated steam, or superheated steam.

The term dry steam is commonly used as the opposite to wet steam, the term is objectionable in that it does not fully define.

Ques. What is superheated steam?

Ans. Steam having a temperature *higher* than that corresponding to its pressure.

Ques. What is gaseous steam, or steam gas?

Ans. An objectionable term for highly superheated steam.

The Formation of Steam.—When heat is transferred to water, at its point of maximum density, it expands as before stated, and continues to do so as the temperature rises until a point is reached where there is no further rise of temperature. This is the temperature at which a second *change of state* takes place; that is to say, the original pound of ice, which has already been changed into water, is now changed into a pound (weight not pressure) of steam. The temperature at which this change takes place is called the *boiling point*.

Ques. Upon what does the boiling point depend?

Ans. Upon the pressure.

Ques. What is the boiling point of water at atmospheric pressure.

Ans. 212° F.

Corresponding to 14.7 lbs. absolute pressure, or 29.92 inches of mercury (*Marks and Davis*).

Ques. What is the pressure of the atmosphere at sea level?

Ans. 14.75 pounds referred to a 30-inch barometer.

Ques. How does the pressure of the atmosphere vary?

Ans. With the elevation, temperature and humidity.

When the barometer reads 30 inches at sea level, the pressure of the air is 14.75 pounds per square inch; at ¼ of a mile above sea level it is 14.02

pounds; at ½ mile, 13.33; at ¾ mile, 12.66; at 1 mile, 12.02; at 1¼ mile, 11.42; at 1½ mile, 10.88; and at 2 miles, 9.8 pounds per square inch.

Latent Heat.—When water at atmospheric pressure has been heated to 212° F., no further expansion takes place while it is in the liquid state, although the supply of heat be continued. Moreover, its temperature remains stationary, and considerable heat must be added to the liquid to transform it into steam, this is known as the *latent heat of vaporization*, and may be defined as *the amount of heat necessary to convert one pound of the liquid at the boiling point into saturated steam of the same temperature*.

Vaporization.—This is the change of state of a substance from the liquid to the gaseous form, which takes place throughout the mass of the liquid.

Ques. How is the vapor formed?

Ans. Both by evaporation and by boiling.

In the first instance, the change takes place at the surface of the liquid only, and in the second instance, it proceeds over the heating surface.

Ques. Describe in detail the process of boiling.

Ans. When heat is applied to a liquid such as a quantity of water in a boiler, the lower layers are first warmed. These expand and rise to the top, their place being taken by the colder layers from above, and by this process the mass is warmed through. The air which is contained in the water expands as the temperature is raised, and rises to the top. The temperature of the lower layers in time becomes raised up to slightly above the atmospheric boiling point, 212° F., and steam is formed, as bubbles adhering to the heating surface; these bubbles, by expansion, become large enough to detach themselves and rise into the colder layers above. On reaching the colder layers, they condense and their sudden collapse sets up vibration in the water which is communicated to the metal of the containing vessel, causing the familiar "singing" heard at this stage, and the steam which composes the bubbles gives up its latent heat, thus warming the water until the whole mass is at the boiling point.

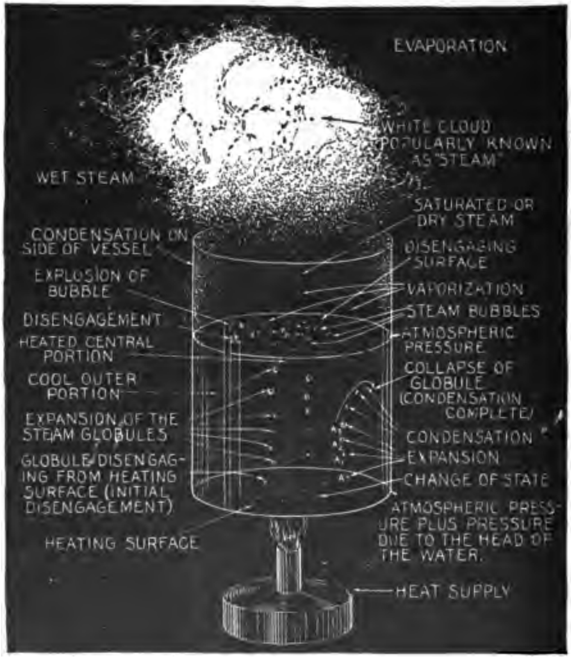

EVAPORATION
WHITE CLOUD POPULARLY KNOWN AS "STEAM"
WET STEAM
SATURATED OR DRY STEAM
CONDENSATION ON SIDE OF VESSEL
DISENGAGING SURFACE
EXPLOSION OF BUBBLE
VAPORIZATION
STEAM BUBBLES
DISENGAGEMENT
ATMOSPHERIC PRESSURE
HEATED CENTRAL PORTION
COLLAPSE OF GLOBULE (CONDENSATION COMPLETE)
COOL OUTER PORTION
EXPANSION OF THE STEAM GLOBULES
CONDENSATION
EXPANSION
GLOBULE DISENGAGING FROM HEATING SURFACE (INITIAL DISENGAGEMENT)
CHANGE OF STATE
ATMOSPHERIC PRESSURE PLUS PRESSURE DUE TO THE HEAD OF THE WATER.
HEATING SURFACE
HEAT SUPPLY

FIG. 3,315.—The phenomena of ***vaporization*** or process of boiling as described in the accompanying text.

When this stage is reached the steam rises to the surface and escapes into the atmosphere and the "singing" ceases, that is to say, *the water is boiling.*

Ques. Why is the temperature of the steam bubbles, as they form on the heating surface, slightly above 212° F.?

Ans. Because the pressure at the bottom of the vessel is greater than the atmospheric pressure, being equal to the latter plus the pressure due to the head of water in the boiler.

The Work of Vaporization.—The amount of work that is done in making one pound of steam at atmospheric pressure from one pound of water at a temperature of 32° F. may be divided into three separate and distinct stages.

STAGE 1.—*The work to raise the temperature of the water from 32° to 212°.*

STAGE 2.—*The work required to bring the water to the point of vaporization.*

STAGE 3.—*The work required to make room for the steam against the pressure of the atmosphere or surrounding medium.*

STAGE 1.—The Sensible Heat.—In stage 1 of the preceding paragraph, the work required to raise the temperature from 32° to 212° is represented by

212°—32°=180°, or 180 heat units.

since the amount of water is one pound. This is called the *sensible heat*, as distinguished from the latent heat, because it is recorded by a thermometer, and is, therefore, sensible to the touch. Since a heat

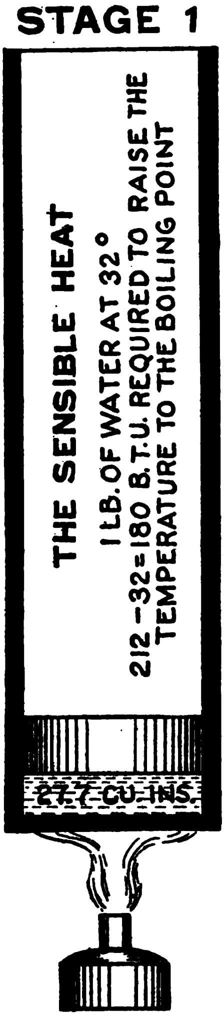
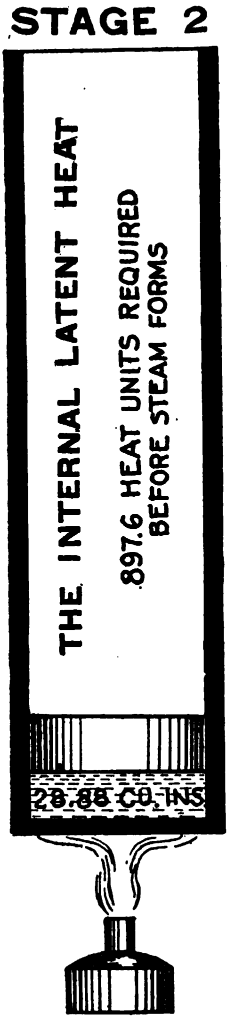

STAGE 1
THE SENSIBLE HEAT
1 LB. OF WATER AT 32°
212−32=180 B.T.U. REQUIRED TO RAISE THE TEMPERATURE TO THE BOILING POINT
27.7 CU. INS.

FIG. 3,316.—*STAGE 1; the sensible heat.* To raise the temperature from 32° to 212° requires 212−32=180 heat units.

unit may be expressed by the mechanical equivalent (778 foot pounds) the sensible heat, or

180 heat units = 180×778 = 140,040 ft. lbs.



STAGE 2—The Latent Heat.—Stages 2 and 3, as given above, comprise the work corresponding to the *latent heat of steam*, of which stage 2 is the *internal latent heat* and stage 3 the *external latent heat*.

The Internal Latent Heat.—To understand just what the internal latent heat is, consider a pound of water at a temperature of 212° throughout; suppose the water to be in a beaker and placed over the flame of a bunsen burner.

The heat now being added to the water will cause small bubbles of steam to form on the heating surface, and since these are formed at a pressure a little greater than that of the atmosphere (because of the head of water) the temperature of the steam thus formed is a little higher than that of the water.

Each bubble first appears as a very minute globule, which expands until its buoyancy overcomes the tension with the heating surface, when it detaches itself.

FIG. 3,317.—*Stage 2; the internal latent heat*, or the amount of heat which must be given to the water at 212° before steam begins to form.

During its upward course toward the surface of the water, the lesser temperature of the water causes it to condense and in so doing it gives up its latent heat to the mass of water.

This process continues until the water has absorbed 897.6 heat units, at which time the bubbles of steam begin to break through the surface of the water and detach themselves therefrom. Up to this point, as stated, the water has absorbed 897.6 heat units at 212°, known as the ***internal** latent heat*, which is represented in work as

$$897.6 \times 778 = 698{,}332.8 \text{ ft. lbs.}$$

It should be noted at this point, that it requires

$$698{,}332.8 \div 140{,}040 = 4.96$$

times as much work or its equivalent in heat units to bring water at 212° to the critical point where vaporization begins, as it does to heat it from 32 to 212°.

The External Latent Heat.—When vaporization begins, that is to say, when the liquid has received sufficient heat so that the steam bubbles formed on the heating surface are able to reach the upper surface and discharge the contained steam, work is done in pushing back the atmosphere against its pressure to make room for the steam. In order to do this work, each steam bubble must contain a corresponding amount of heat, which is known as the ***external** latent heat* as distinguished from the ***internal** latent heat*.

The work done by the steam in making room for itself against the pressure of the superincumbent atmosphere (or steam if enclosed in a vessel) is called the ***external work of vaporization***.

In order to determine the value of the external latent heat, it is necessary to compute the external work of vaporization, from which the external latent heat is easily found by means of the mechanical equivalent of heat.

The External Work of Vaporization.—In the formation of steam, external work must be done in pushing away the atmosphere, which exerts a pressure of 14.7 pounds per square inch upon the water, to make room for the steam.

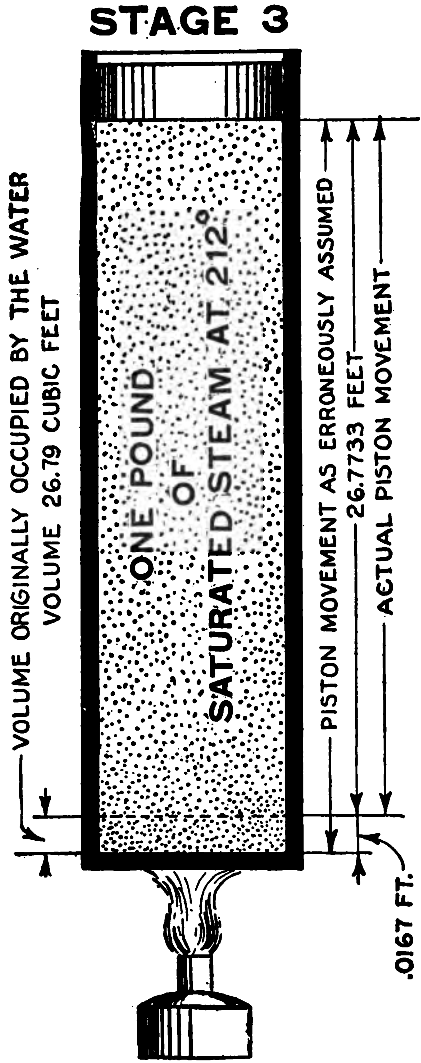

STAGE 3
VOLUME ORIGINALLY OCCUPIED BY THE WATER
VOLUME 26.79 CUBIC FEET
ONE POUND OF SATURATED STEAM AT 212°
PISTON MOVEMENT AS ERRONEOUSLY ASSUMED
26.7733 FEET
ACTUAL PISTON MOVEMENT
.0167 FT.

FIG. 3,318.—***Stage 3: the external latent heat***, or heat converted into work by the steam in making room for itself against the pressure of the superincumbent atmosphere. The author does not agree with the generally accepted calculation for the external work of vaporization, and holds that it is wrong in principle. The common method of calculating this work is to consider the movement of the piston equal to the distance between the bottom of the cylinder and the piston or 26.79 feet which would give for the external work

$$144 \times 14.7 \times 26.79 = 56,709.07 \text{ ft. lbs.}$$

Motion is purely a relative matter, and accordingly something must be regarded as being stationary as a basis for defining motion, hence the question: *Should the movement of the piston be referred to a stationary water level or to a receding water level?* The author holds that the movement of the piston referred to a stationary water level gives the true displacement of the air and is accordingly the proper basis for calculating the external work. It must be evident that since the water already existed at the beginning of vaporization, the atmosphere was already displaced to the extent of the volume occupied by the water, and therefore this displacement must not be considered as contributing to the external work done by the steam during its formation. Calculating on this basis, the external work equals

$$144 \times 14.7 \times 26.7733 = 56,673.72 \text{ ft. lbs.}$$

being *less* than the amount as ordinarily calculated by

$$56,709.07 - 56,673.72 = 35.35 \text{ ft. lbs.}$$

The amount of error (35.35 ft. lbs.) of the common calculation, though very small, is an appreciable amount, especially when expressed in foot pounds. Its equivalent in heat units is:

$$35.35 \div 777.52 = .0455 \textit{ B.t.u.}$$

and the thermal equivalent of the external work is:

$$56,673.72 \div 777.52 = 72.89 \textit{ B.t.u.}$$

Now, the volume of one pound of water at 212° (atmospheric pressure) is 28.88 cubic inches, and, if this water be placed in a long cylinder, as in fig. 3,317, having a cross sectional area of 144 square inches, it will occupy a depth of .2 inch or .0167 foot. If a piston (assumed to have no weight and to move without friction) be placed on top of the water, as in fig. 3,317 and heat be applied, vaporization will begin, and when all the water has changed into saturated steam, the volume has increased to 26.79 cubic feet, as in fig. 3,318, that is to say, the volume of one pound of saturated steam at atmospheric pressure is 26.79 cubic feet.

Since the area of the piston is 1 square foot, the linear distance from the bottom of the cylinder to the piston is 26.79 feet, *but the piston has not moved this distance.* The initial position of the piston being .0167 foot above the bottom of the cylinder, its actual movement is 26.79 — .0167 = 26.7733 feet.

Accordingly, the external work done by the steam in moving the piston against the pressure of the atmosphere to make room for itself is,

$$= \textit{area piston} \times \textit{pressure of atmosphere} \times \textit{movement of piston} = \textit{external work}$$

$$144 \text{ sq. ins.} \times 14.7 \text{ lbs.} \times 26.7733 \text{ ft.} = 56{,}673.72 \text{ ft. lbs.}$$

The Total Heat of Saturated Steam.—In transforming one pound of water into saturated steam at atmospheric pressure the amount of heat to be supplied, as already shown, may be tabulated as follows:

Stage 1.—The sensible heat required to raise the temperature of the water to the boiling point........................	180	*B.t.u.*
Stage 2.—The internal latent heat absorbed by the water at 212° before a change of state takes place................	897.51	" " "
Stage 3.—The external latent heat required for the work to be done on the atmosphere........................	72.89	" " "
	1,150.4	" " "

The sum of these three items, is known as *the total heat above 32° F.*, this temperature being taken as the starting point.

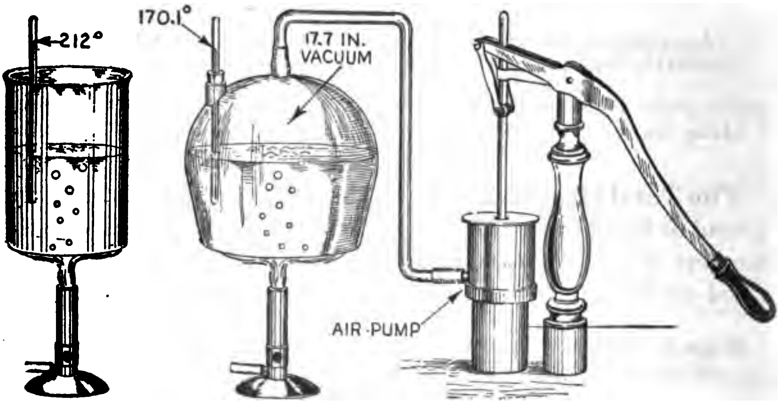
Expressed as an equation.

$$\textit{Sensible heat} + \textit{internal latent heat} + \textit{external latent heat} = \textit{total heat}$$

$$180 + 897.51 + 72.89 = 1{,}150.4\ \textit{B.t.u.}$$

It should be noted that the sensible heat is said to be ***in the water*** and the total heat ***in the steam.***

The Boiling Point.—Water in an open vessel boils at a temperature of 212° F. when the barometer reads 30 inches. Now, if the vessel be closed, and the supply of heat be continued, the pressure of the steam will gradually rise, and the temperature of the liquid also; that is to say, the boiling point is elevated above 212° when the pressure is increased above 14.7 pounds, *there being a definite temperature or boiling point corresponding to each value of pressure;* in other words, there is one temperature only for steam at any given pressure; at any other pressure, the temperature has some other value, but always fixed for that particular pressure.



Figs. 3,319 and 3,320.—The ***boiling point***. The temperature at which water boils depends upon the pressure. Thus, at atmospheric pressure as in fig. 3,319, water boils at 212° Fahr., but under say a 17.7 inch vacuum (at 6 pounds absolute pressure) it boils at 170.1°.

Ques. When vaporization takes place in a closed vessel what happens if the temperature rise?

Ans. The pressure rises until equilibrium between temperature and pressure is re-established.

Ques. If the temperature be lowered, what happens?

Ans. Condensation takes place and the pressure decreases until equilibrium is re-established between temperature and pressure.

Ques. What is condensation?

Ans. The change of state of a substance from the gaseous to the liquid form.

Ques. What causes condensation?

Ans. A reduction of temperature below that corresponding to the pressure.

Ques. What happens when steam condenses?

Ans. The water from which the steam was formed originally contained a small percentage of air mechanically mixed with it, and this air does not re-combine with the water of condensation, but remains liberated—in the case of a steam heating plant in the pipes.

Thus the necessity for air relief valves. Again in the case of a condensing engine, the liberated air must be removed from the condenser in addition to the condensate to maintain a vacuum.

How a Boiler Makes Steam.—If a pot filled with water, be placed on an open fire, as shown in fig. 3,321, it will be noticed when it boils that the water heaves up at the sides and plunges down in the center. This is due to the water being heated most at the sides, causing it to expand and become lighter. Consequently, it rises and on reaching the surface is cooled somewhat, which causes it to contract, and becoming denser it naturally sinks.

The formation of steam takes place in the water directly in contact with the pot, especially in the lower part where the temperature of the metal is highest.

In the formation of steam, a particle of water in contact with the metal is heated until it is changed into steam, first appearing as a small bubble, which for a time clings to the metal. The size of the bubble gradually increases by the addition of more steam, formed from the surrounding water until finally it disengages itself from the metal. Since it is much lighter than the water, it quickly rises and bursts on reaching the surface, allowing the steam to escape into the atmosphere.

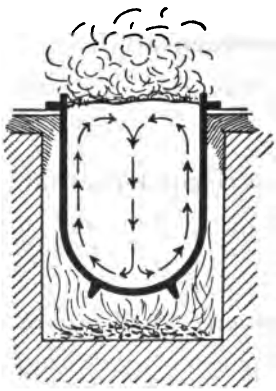


FIG. 3,321.—Circulation of water in boiling. The lower and outer layers are first warmed. These expand, and becoming less dense, rise to the surface, their place being taken by the colder and denser layers thus producing convection currents as indicated by the arrows.

In fig. 3,321 the natural circulation of the water with a moderate fire is up around the sides of the vessel and down in the central part. If the fire be very hot, steam bubbles will rise from all points at the bottom in such quantities as to impede the downward flow of the water, in which case the pot "boils over." This may be prevented if a vessel of somewhat smaller diameter with a hole in the bottom, be lowered into the pot as shown in fig. 3,322, fastened in such a manner so as to leave a space all around between it and the pot. The upward currents are then separated from the downward, and the fire can be forced to a greater extent than before without boiling over. This simple arrangement is the basis of many devices for securing free circulation of the water in steam boilers.

The importance of a free circulation is, among other things, to maintain the boiler at a uniform temperature, so as to prevent unequal expansion in its various parts, especially in boilers having thick plates, and also to facilitate the escape of steam from the heating surface as soon as it is formed.

This is necessary to prevent overheating of the plates, which would occur unless they be maintained in constant contact with the water.

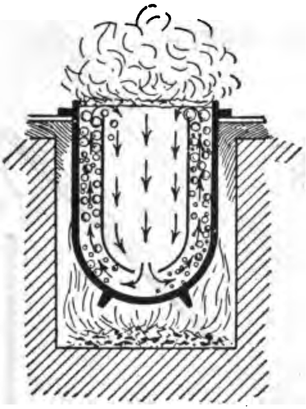


Fig. 3,322.—Why a pot "boils over." A heavy fire applied to the arrangement shown in fig. 3,321 will cause violent agitation at the surface by the unguided currents. If an inner vessel with openings at bottom and top be inserted in the pot, as here shown, it will act as a guide and separate the ascending and descending currents; the water then will boil more smoothly.

The principle of circulation as applied to the steam boiler is shown more clearly in fig. 3,324.

A U-shaped tube is connected to a vessel and filled with water. Heat is applied to one leg, B, and as the water in this leg is warmed, it expands and hence becomes lighter.

The heavier water in A, consequently sinks and forces the less dense water in B, up into the vessel at the top. A circulation or flow of water is thus produced as indicated by the arrows.

At first the water flows slowly, its rate depending on the difference in temperature between the water in the two legs; when steam bubbles form in B, the circulation is greatly increased as the mixture of water and steam in B, is much lighter than the water in A.

In order to generate steam faster, it is necessary to increase the heating surface. This may be done by extending the heated vertical leg B, into a long incline, beneath which may be placed three lamps instead of one, as shown in fig. 3,325. The direction of the circulation is the same, but its rate is increased.

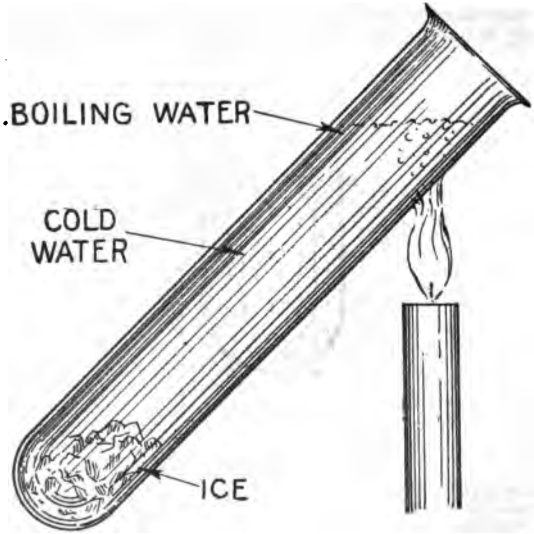


FIG. 3,323.—Experiment to show the *importance of circulation in boilers*. Water is a bad conductor, and receives heat principally by convection. A test tube filled with cold water having a piece of ice placed in the lower end, is heated at the top as shown. The water will soon boil at its upper surface while the temperature of the bottom of the tube is not appreciably changed.

A further improvement results from increasing the number of tubes, keeping them all inclined so that the heated water and steam may rise freely, as shown in fig. 3,326.

In a steam boiler the burning fuel is enclosed either by fire brick or a water jacket consisting of a double coating of metal plates with a space between which is filled with water. *On any type of boiler, a considerable amount of the heat generated by the fuel is lost.*

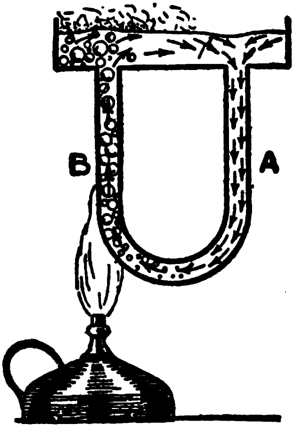


FIG. 3,324.—Circulation of water in boilers. As heat is applied to the "up flow" or "riser" B, the water in it expands, and becoming less dense is displaced by the colder and heavier water in the "down flow" A, thus causing the water to circulate as indicated by the arrows.

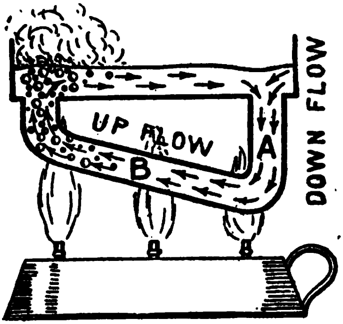


FIG. 3,325.—Inclined tube method of obtaining circulation of water in water tube boilers. *In operation,* the colder water flows down in the *down flow* tube A, and up in the *up flow* tube B. The inclined position of B, prevents any steam bubbles escaping through A, hence the steam bubbles, greatly decreasing the density of the water column in B, causes rapid circulation.

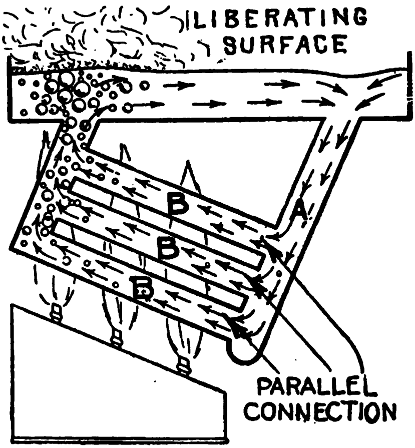


FIG. 3,326.—Elementary boiler illustrating ***parallel*** connection of the tubes. As constructed, a boiler contains many up flow tubes B; to divide the water into many small streams and present considerable heating surface to the fire so as to generate steam faster. The tubes are usually inclined 15° to aid the circulation. In the arrangement here shown the tubes are connected ***in parallel.***

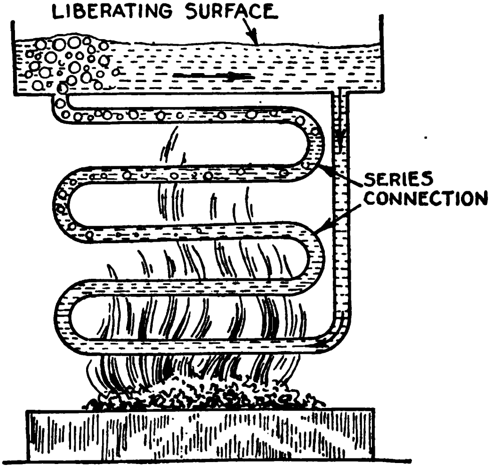


FIG. 3,327.—Elementary boiler illustrating ***series*** connection of the tubes. In the arrangement the end of one tube is joined to the end of the next, as shown. When thus joined the tubes are said to be connected ***in series.***

Factors of Evaporation.—It takes more coal to generate steam at high pressure than at low pressures, and accordingly in the rating of steam boilers some standard of evaporation must be adopted in order to obtain a true measure of performance. This involves two items.

1. Temperature of the feed water;
2. Pressure at which the steam is generated.

With respect to the first item, it must be evident that more coal would be used in generating steam if the feed water were supplied at a low temperature, say 60° F, than at a higher temperature, say 150° F. and no comparison of the performance of two boilers working under these conditions could be obtained, unless a factor were introduced in the calculation to allow for the difference in temperature of the feed water. The reason more heat is required as the pressure of the steam is raised may be less apparent.

Ques. Why is more coal required to generate steam at a high pressure than at a low pressure?

Ans. The external work of vaporization is greater.

That is to say, more work is done in the formation of the steam in making room for itself against a high pressure than against a low pressure.

Ques. How is a standard of vaporization obtained?

Ans. By finding the equivalent vaporization "*from and at 212° Fahr.*"

Ques. What is the meaning of the term "from and at 212° Fahr.?"

Ans. It signifies the generation of steam at 212° F. from water at the same temperature.

Ques. Define the term "factor of evaporation."

Ans. A factor of evaporation is a *quantity which when multiplied by the amount of steam generated at a given pressure from*

water at a given temperature, gives the equivalent evaporation from and at 212° Fahr.

Ques. How is the factor of evaporation obtained?

Ans. It is equal to the difference in the heat in the steam at the pressure generated, and the heat in the water divided by the latent heat of steam at atmospheric pressure.

Expressed as a formula:

$$F=\frac{H-h}{H'-h'} \qquad \text{.............................(1)}$$

in which
F = Factor of Evaporation.
H = Heat above 32° Fahr. in the steam at given pressure.
h = Heat above 32° Fahr. in water at given pressure.
H' = Heat above 32° Fahr. in steam at atmospheric pressure.
h' = Heat above 32° Fahr. in water at atmospheric pressure.

Formula (1) just given is expressed in the simplest form as

$$\mathrm{F}=\frac{H-h}{970.4} \qquad \text{.............................(2)}$$

Here $970.4=H'-h'=1150.4-180$ (see steam table)

Example—What is the factor of evaporation for steam at 200 pounds pressure when the feed water is delivered to the boiler at a temperature of 150° Fahr.? From the steam table, the heat H, in the steam at 200 pounds pressure = 1,200.2 *B.t.u.* The heat h, in the feed water *above 32°* at 150° Fahr. is $150-32=118$ *B.t.u.* Substituting these values in formula 2

$$F=\frac{1{,}199.2-118}{970.4}=1.1121$$

The meaning of it is that if a boiler were generating, say 1,000 pounds of steam per hour at 200 pounds pressure, from feed water at 150° Fahr. it would absorb the same amount of heat from the fire as when generating

$$1{,}000\times 1.1121=1{,}112 \text{ lbs.}$$

of steam "*from and at 212°*", that is generating steam at atmospheric pressure from feed water at 212°.

Ques. How is the calculation of the equivalent evaporation from and at 212° F. facilitated?

Ans. By means of a table giving the factors of evaporation from various pressures and feed water temperatures, such as is given on page 1,808.

Example.—A boiler evaporates 1,000 pounds of steam at 95 pounds gauge pressure and the feed water is heated to 110°. How much steam will it evaporate *from and at 212°*?

Referring to the table on page 1,808, the factor of evaporation for steam at 95 lbs. pressure with feed water at 110°, is 1.145.

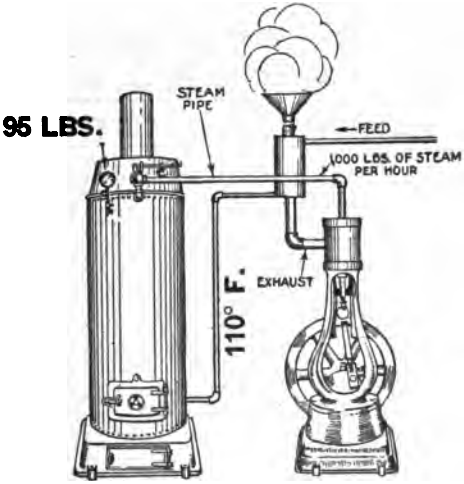


Fig. 3,328.—Ordinary steam plant illustrating the condition of operation mentioned in the above example.

If the feed water be heated to 212° and the steam be generated at atmospheric pressure, the boiler will then evaporate

$$1{,}000 \times 1.145 = 1{,}145 \text{ lbs. of steam}$$

Saving Due to Heating the Feed Water.—In exhaust steam heating installations where only part of the steam from the

Factors of Evaporation

Temperature Feed Water. Fahrenheit.	PRESSURE IN POUNDS PER SQUARE INCH ABOVE THE ATMOSPHERE.																					Temperature Feed Water. Fahrenheit.
	0	5.	15.	25.	35.	45.	55.	65.	75.	85.	95.	105.	115.	125.	135.	145.	155.	165.	175.	185.	200.	
Degr's																						Degr's
32	1.187	1.192	1.199	1.204	1.209	1.212	1.216	1.218	1.221	1.223	1.226	1.228	1.230	1.231	1.233	1.235	1.236	1.238	1.239	1.240	1.241	32
35	1.184	1.189	1.196	1.201	1.206	1.209	1.213	1.215	1.218	1.220	1.223	1.225	1.227	1.228	1.230	1.232	1.233	1.235	1.236	1.237	1.238	35
40	1.179	1.184	1.191	1.196	1.201	1.204	1.208	1.219	1.213	1.215	1.218	1.220	1.222	1.223	1.225	1.227	1.228	1.230	1.231	1.232	1.233	40
45	1.173	1.178	1.185	1.190	1.195	1.198	1.202	1.204	1.207	1.209	1.212	1.214	1.216	1.217	1.219	1.221	1.222	1.224	1.225	1.226	1.227	45
50	1.168	1.173	1.180	1.185	1.190	1.193	1.197	1.199	1.202	1.204	1.207	1.209	1.211	1.212	1.214	1.216	1.217	1.219	1.220	1.221	1.222	50
55	1.163	1.168	1.175	1.180	1.185	1.188	1.192	1.194	1.197	1.199	1.202	1.204	1.206	1.207	1.209	1.211	1.212	1.214	1.215	1.216	1.217	55
60	1.158	1.163	1.170	1.175	1.180	1.183	1.187	1.189	1.192	1.194	1.197	1.199	1.201	1.202	1.204	1.206	1.207	1.209	1.210	1.211	1.212	60
65	1.153	1.158	1.165	1.170	1.175	1.178	1.182	1.184	1.187	1.189	1.192	1.194	1.196	1.197	1.199	1.201	1.202	1.204	1.205	1.206	1.207	65
70	1.148	1.153	1.160	1.165	1.170	1.173	1.177	1.179	1.182	1.184	1.187	1.189	1.191	1.192	1.194	1.196	1.197	1.199	1.200	1.201	1.202	70
75	1.143	1.148	1.155	1.160	1.165	1.168	1.172	1.174	1.177	1.179	1.182	1.184	1.186	1.187	1.189	1.191	1.192	1.194	1.195	1.196	1.197	75
80	1.137	1.142	1.149	1.154	1.159	1.162	1.166	1.168	1.171	1.173	1.176	1.178	1.180	1.181	1.183	1.185	1.186	1.188	1.189	1.190	1.191	80
85	1.132	1.137	1.144	1.149	1.154	1.157	1.161	1.163	1.166	1.168	1.171	1.173	1.175	1.176	1.178	1.180	1.181	1.183	1.184	1.185	1.186	85
90	1.127	1.132	1.139	1.144	1.149	1.152	1.156	1.158	1.161	1.163	1.166	1.168	1.170	1.171	1.173	1.175	1.176	1.178	1.179	1.180	1.181	90
95	1.122	1.127	1.134	1.139	1.144	1.147	1.151	1.153	1.156	1.158	1.161	1.163	1.165	1.166	1.168	1.170	1.171	1.173	1.174	1.175	1.176	95
100	1.117	1.122	1.129	1.134	1.139	1.142	1.146	1.148	1.151	1.153	1.156	1.158	1.160	1.161	1.163	1.165	1.166	1.168	1.169	1.170	1.171	100
105	1.111	1.116	1.123	1.128	1.133	1.136	1.140	1.142	1.145	1.147	1.150	1.152	1.154	1.155	1.157	1.159	1.160	1.162	1.163	1.164	1.165	105
110	1.106	1.111	1.118	1.123	1.128	1.131	1.135	1.137	1.140	1.142	1.145	1.147	1.149	1.150	1.152	1.154	1.155	1.157	1.158	1.159	1.160	110
115	1.101	1.106	1.113	1.118	1.123	1.126	1.130	1.132	1.135	1.137	1.140	1.142	1.144	1.145	1.147	1.149	1.150	1.152	1.153	1.154	1.155	115
120	1.096	1.101	1.108	1.113	1.118	1.121	1.125	1.127	1.130	1.132	1.135	1.137	1.139	1.140	1.142	1.144	1.145	1.147	1.148	1.149	1.150	120
125	1.091	1.096	1.103	1.108	1.113	1.116	1.120	1.122	1.125	1.127	1.130	1.132	1.134	1.135	1.137	1.139	1.140	1.142	1.143	1.144	1.145	125
130	1.085	1.090	1.097	1.102	1.107	1.110	1.114	1.116	1.119	1.121	1.124	1.126	1.128	1.129	1.131	1.133	1.134	1.136	1.137	1.138	1.139	130
135	1.080	1.085	1.092	1.097	1.102	1.105	1.109	1.111	1.114	1.116	1.119	1.121	1.123	1.124	1.126	1.128	1.129	1.131	1.132	1.133	1.134	135
140	1.075	1.080	1.087	1.092	1.097	1.100	1.104	1.106	1.109	1.111	1.114	1.116	1.118	1.119	1.121	1.123	1.124	1.126	1.127	1.128	1.129	140
145	1.070	1.075	1.082	1.087	1.092	1.095	1.099	1.101	1.104	1.106	1.109	1.111	1.113	1.114	1.116	1.118	1.119	1.121	1.122	1.123	1.124	145
150	1.065	1.070	1.077	1.082	1.087	1.090	1.094	1.096	1.099	1.101	1.104	1.106	1.108	1.109	1.111	1.113	1.114	1.116	1.117	1.118	1.119	150
155	1.059	1.064	1.071	1.076	1.081	1.084	1.088	1.090	1.094	1.095	1.098	1.100	1.102	1.103	1.105	1.107	1.108	1.110	1.111	1.112	1.113	155
160	1.054	1.059	1.066	1.071	1.076	1.079	1.083	1.085	1.088	1.090	1.093	1.095	1.097	1.098	1.100	1.102	1.103	1.105	1.106	1.107	1.108	160
165	1.049	1.054	1.061	1.066	1.071	1.074	1.078	1.080	1.083	1.085	1.088	1.090	1.092	1.093	1.095	1.097	1.096	1.100	1.101	1.102	1.103	165
170	1.044	1.049	1.056	1.061	1.066	1.069	1.073	1.075	1.078	1.080	1.083	1.085	1.087	1.088	1.090	1.092	1.093	1.095	1.096	1.097	1.098	170
175	1.039	1.044	1.051	1.056	1.061	1.064	1.068	1.070	1.073	1.075	1.078	1.080	1.082	1.083	1.085	1.087	1.088	1.090	1.091	1.092	1.093	175
180	1.033	1.038	1.045	1.050	1.055	1.058	1.062	1.064	1.067	1.069	1.072	1.074	1.076	1.077	1.079	1.081	1.082	1.084	1.085	1.086	1.087	180
185	1.028	1.033	1.040	1.045	1.050	1.053	1.057	1.059	1.062	1.064	1.067	1.069	1.071	1.073	1.074	1.076	1.077	1.079	1.080	1.081	1.082	185
190	1.023	1.028	1.035	1.040	1.045	1.048	1.052	1.054	1.057	1.059	1.062	1.064	1.066	1.067	1.069	1.071	1.072	1.074	1.075	1.076	1.077	190
195	1.018	1.023	1.030	1.035	1.040	1.043	1.047	1.049	1.052	1.054	1.057	1.059	1.061	1.062	1.064	1.066	1.066	1.069	1.070	1.071	1.072	195
200	1.013	1.018	1.025	1.030	1.035	1.038	1.042	1.044	1.047	1.049	1.052	1.054	1.056	1.057	1.059	1.061	1.062	1.064	1.065	1.066	1.067	200
205	1.001	1.012	1.019	1.024	1.029	1.032	1.036	1.038	1.041	1.043	1.046	1.048	1.050	1.051	1.053	1.055	1.056	1.058	1.059	1.060	1.062	205
210	1.002	1.007	1.014	1.019	1.024	1.027	1.031	1.033	1.036	1.038	1.041	1.043	1.045	1.046	1.048	1.060	1.051	1.053	1.054	1.055	1.057	210
212	1.000	1.005	1.012	1.017	1.022	1.025	1.029	1.031	1.034	1.036	1.039	1.041	1.043	1.044	1.046	1.048	1.049	1.061	1.052	1.058	1.056	212

engine is used for heating, the unused portion from the engine and also from the auxiliaries can be used to advantage in heating the feed water resulting in an approximate saving of 1 per cent. for each increase of 11° in the temperature of the feed water; this corresponds to a saving of .0909 per cent. per degree.

The calculation is made from the following formula:

$$\text{Saving by heating feed water} = \frac{h' - h}{H - h}$$

in which

H = total heat in 1 pound of steam at the boiler pressure.
h = total heat in 1 pound of feed water *before* entering heater.
h' = total heat in 1 pound of feed water after passing through heater.

Example.—If the boiler pressure be 80 pounds gauge, initial temperature of feed water 60°, and final temperature 209° F., what is the saving? Referring to the Steam Table, the total heat H, above 32° Fahr. in steam at 80 lbs. gauge is 1,185.4 *B.t.u.* Substitute the formula:

$$\text{Saving} = \frac{209 - 60}{1{,}185.4 - 60} = .1324, \text{ that is, } 13.24\%$$

Example.—What is the saving due to heating the feed water from 60° to 202°, when the steam pressure is 150 pounds (gauge)?

From the steam table:

Total heat in 1 pound steam at 150 pounds = 1,195
Total heat in 1 pound feed water at 60° = 28.08

Heat required to form 1 pound steam......... 1,166.92

also

Total heat in 1 pound feed water at 202° = 169.95
Total heat in 1 pound feed water at 60° = 28.08

Heat units saved.......................... 141.87

Since 141.87 heat units are saved, the heat required to generate 1 pound of steam is

$$1{,}166.92 - 141.87 = 1{,}025.05$$

and the percentage is

$$142.87 \div 1{,}025.05 = 13.84\%$$

Superheated Steam.—If a closed vessel containing water and steam be heated, the pressure of the steam will gradually rise until all the water has been evaporated. At this point the further addition of heat will not produce any appreciable increase in pressure but will cause a rise in temperature in which condition the steam is said to be *superheated*, hence, superheated steam is defined as *steam heated to a temperature above that due to its pressure.*

Specific Heat of Superheated Steam.—In Marks & Davis' work the classical research of Regnault, published in the year 1862, has been consulted.

"Contrary to an assumption sometimes seen in the literature, his work does not even seem to prove that the specific heat at constant pressure (C_p) of superheated steam is independent of either the pressure or the temperature, for he made only four series of experiments, and these were all at atmospheric pressure and covered nearly the same temperature range. He worked by the method of mixtures, injecting a known weight, first of slightly superheated steam, and then of highly superheated steam, into a calorimeter filled with water at room temperature. His computations are in error because, instead of weighing the cold water in the calorimeter, he measured it volumetrically in a suitable cast-iron tank. His justification of this was that although, by reason of the thermal expansion of the water as compared with that of the tank, there was less water by weight at room temperature than at O°C., which was his standard temperature, nevertheless, the fact (which he thought to be true at low as well as at high temperatures), that the specific heat of water increased with the temperature, made the water in the calorimeter more effective thermally, gram for gram, and just about made up for neglecting its change of density. But we now know that at room temperatures the specific heat of water decreases with rising temperature. His data have, therefore, been recomputed, using his own value for the expansion coefficient of his sheet iron tanks and modern data for the density and specific heat of water. This slightly reduces each of his four values of C_p to the following figures:

	Temp. Range (C°)	R's Value of C_p	New Value of C_p
Series 1...	127.7—231.1	(.46881)[1]	(.4655)
Series 2...	137.7—225.9	.48111	.4769
Series 3...	124.3—210.4	.48080	.4736
Series 4...	122.8—216.0	.47963	.4780
	Mean of last three	.48051	.4762

—*From Marks and Davis' Steam Tables.*

Quality of the Steam.—There is generally more or less water or moisture carried over in steam from the boiler, depending on the type, height of the water, and rate at which the boiler is operated. For comparison, engine and boiler performance must be reduced to a standard basis of saturated steam, hence some means is necessary for determining the quality of the steam. This is done by a device called a calorimeter; there are three types in general use:

1. The barrel;
2. The throttling;
3. The separating.

The barrel calorimeter was invented by the Alsatian engineer, G. A. Hine. It is an early form, and though not very accurate, is useful in rough determinations when there is much water present. With careful operation it may be relied upon to give results within 2 per cent. of being correct. An error of $^1/_{10}$ pound in weighing the combined steam, or an error of ½ a degree in the temperature, will cause an error of over 1% in the calculated percentage of moisture.

The throttling calorimeter is most useful and convenient for percentage of moisture not exceeding 3 per cent.

The separating calorimeter is used when the percentage of moisture is beyond the range of the throttling type. The calculation with this instrument is quite simple, and tests show the steam discharged from it to be practically dry.

The Barrel Calorimeter.—This consists of a barrel placed on weighing scales, as shown in fig. 3,329. The barrel is partly filled with a certain weight of cold water and its temperature ascertained. A steam pipe from the boiler is fitted with a valve, and short length of hose as shown. Steam is blown through the pipe with hose outside the barrel until thoroughly warmed, when the hose is suddenly thrust into the water with the valve still open. An arrangement is fitted to the barrel to stir the water and so keep the temperature uniform.

When the water has reached about 110° the hose is suddenly withdrawn and the water again weighed.

Then, the heat lost by the steam is

$$xL + w\ (t_3 - t_2)$$

and the heat gained by the water is

$$W\ (t_2 - t_1)$$

These two heats must be equal, hence equating and solving for x.

$$x = \frac{W\ (t_2 - t_1) - w\ (t_3 - t_2)}{L}$$

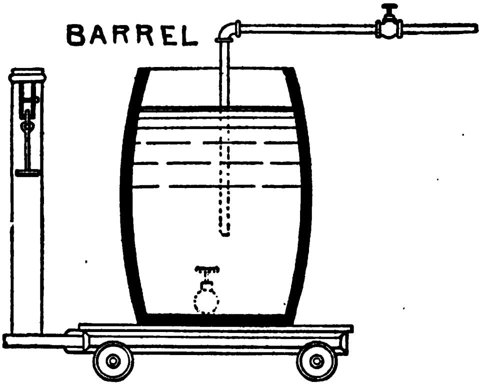


FIG. 3,329.—The barrel calorimeter. With careful operation results may be obtained within two per cent of accuracy. The barrel calorimeter is useful in determining the quality of steam where there is much moisture present.

in the above

x = pounds of dry steam supplied;
w = weight of steam (wet or dry) blown in;
W = original weight of cold water;
L = latent heat of the steam at given pressure;
t_1 = temperature of cold water;
t_2 = temperature of water after addition of steam;
t_3 = temperature of the steam.

The percentage of moisture $= (w-x) \div w \times 100$

Example.—If a barrel or tank contains 200 pounds of water at a temperature of 60° F., and 10 pounds of moist steam be added at a pressure of 85 pounds absolute, thus raising the temperature of the water to 110° F., what is the percentage of moisture in the steam? (Latent heat of steam at 85 pounds pressure absolute = 892. Temperature 316°).

$$x = \frac{W(t_2 - t_1) - w(t_3 - t_2)}{L}$$

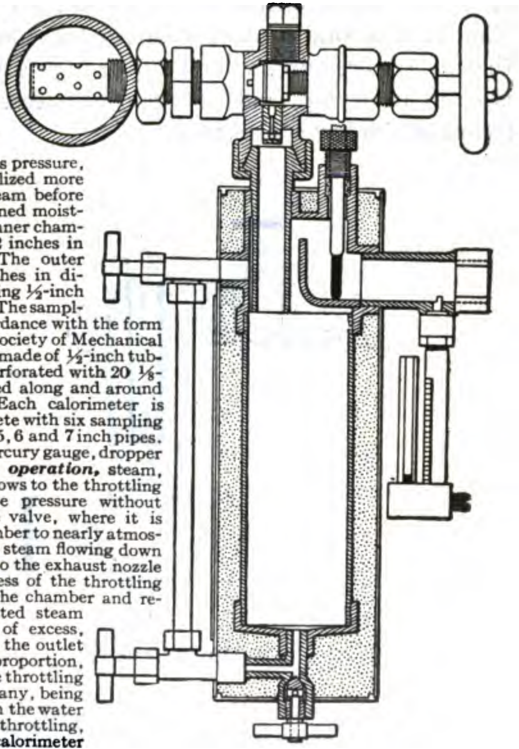


FIG. 3,330.—Ellison throttling calorimeter. ***In principle*** its action depends upon the heat liberated by throttling, which raises the temperature of the steam in the calorimeter above that due to its pressure, the heat liberated being utilized more or less, according as the steam before throttling was dry or contained moisture. ***In construction,*** the inner chamber, or steam chamber, is 2 inches in diameter, 6 inches long. The outer chamber, or jacket, is 3 inches in diameter and 7 inches long, giving ½-inch space between the chambers. The sampling nozzles are made in accordance with the form prescribed by the American Society of Mechanical Engineers. These nozzles are made of ½-inch tubing, closed at the end and perforated with 20 ⅛-inch holes, equally distributed along and around their cylindrical surface. Each calorimeter is packed in a neat case, complete with six sampling nozzles, one each for 2, 3, 4, 5, 6 and 7 inch pipes. Also valve, thermometer, mercury gauge, dropper and bottle of mercury. ***In operation,*** steam, entering the sampling pipe, flows to the throttling plug under full steam pipe pressure without pockets or up turns in the valve, where it is throttled into the steam chamber to nearly atmospheric pressure, the throttled steam flowing down one side and up the other into the exhaust nozzle at the top, moisture in excess of the throttling process being separated in the chamber and re-evaporated by the superheated steam after a momentary period of excess, lowering the temperature on the outlet thermometer in direct proportion, moisture in excess of both the throttling and evaporating processes, if any, being accounted for as separation in the water glass forming a combined throttling, separating and evaporating calorimeter in one chamber, moisture in the up flow falling back and traveling through superheated steam. The ***condenser connection*** is an attachment for connecting the outlet nozzle with the engine condenser for increasing the evaporating range, steam in the lower regions of temperature having high capacity for evaporating moisture, 10 pounds below atmosphere evaporating nearly 2%. It is made of brass, with ¾ in. pipe union, lock nut for nozzle, copper drain tube with cock for connecting with calorimeter drain, mercury gauge being replaced with a ⅛ in. plug.

$$= \frac{200\ (110-60) - 10\ (316-110)}{892} = 8.9 \text{ pounds of dry steam}$$

$$(10 - 8.9) \div 10 \times 100 = 11 \text{ per cent of moisture.}$$

The Throttling Calorimeter.—The principle employed in the throttling calorimeter is that moist steam may be dried and superheated by throttling, the degree of superheat depending on the initial condition of the steam, and degree of throttling. That is, the total heat of steam at high pressure is greater than that at low pressure, and on falling in pressure the excess of heat is spent in drying, and (if sufficient excess) in superheating the steam at the lower pressure.

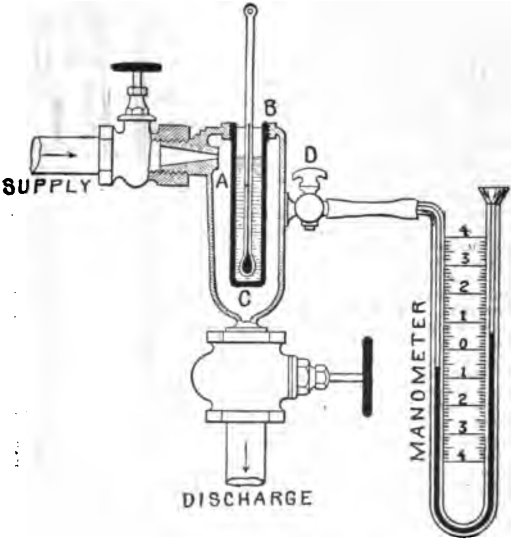


FIG. 3,331.—The throttling calorimeter. Invented in 1888 by Prof. Peabody; its principle of operation is that moist steam may be dried, and superheated by throttling, the degree of superheat depending on the condition of the steam before throttling. The range of the throttling calorimeter is for steam containing from 2 to 3 per cent of moisture.

A throttling calorimeter as shown in fig. 3,331, consists of a chamber having a reducing tube A, through which the steam enters, a pressure regulating valve B, thermometer well C, and a cock D, connecting with a U tube pressure gauge. Steam is throttled through the reducing tube, which terminates in a 1/16-inch orifice, and enters the chamber. The pressure here is reduced to nearly that of the atmosphere, but the total heat in the steam before throttling causes the steam in the chamber to be superheated more or less according to whether the steam before throttling was dry or wet. The only observations required are those of the temperature and pressure of the steam on each side of the orifice.

Example.—The total heat in 1 pound of steam at 100 pounds pressure absolute is 1,182 *B.t.u.*, and that in 1 pound of steam at 20 pounds absolute is 1,151; if the steam were allowed to expand from 100 pounds in the steam pipe to 20 pounds pressure in vessel C, without doing external work, the heat units liberated per pound = (1,182 − 1,151) = 31. If the steam in vessel C, be at 20 pounds absolute pressure, its latent heat is 954 units. Weight of moisture which the excess heat will evaporate will therefore be 31 ÷ 954 = .032 pounds.

If, however, the amount of moisture present were less than this, then the balance of the excess heat would superheat the remaining steam above its normal temperature, and the excess would be shown by the thermometer. In such a case the percentage of moisture may be computed from the formula given below. If the moisture present be greater than the excess heat can evaporate, then no superheating takes place, and this calorimeter would not be applicable. It is, however, very accurate within its range; namely, with steam containing not more than from 2 to 3 per cent. of moisture, now if:

t_1 = temperature of steam in main steam-pipe:
t_2 = temperature in vessel C, into which the steam has been expanded to a lower pressure;
t_3 = normal temperature of steam in C, due to its pressure.

then the total heat per pound of steam carried into calorimeter is:

$$w = h_1 + xL_1$$

In the calorimeter, the heat in the steam due to its reduced pressure, when the moisture is just evaporated is:

$$h_3 + L_3$$

and if there be sufficient excess heat to superheat the steam, then the heat required is

$$.48\ (t_2 - t_3)$$

Then,

$$h_1 + xL_1 = h_3 + L_3 + .48\ (t_2 - t_3)$$

or,

$$x = \frac{h_3 - h_1 + L_3 + .48\ (t_2 - t_3)}{L_1}$$

The Separating Calorimeter.—For percentages of moisture beyond the range of the throttling calorimeter, the separating calorimeter is used, which is simply a separator on a small scale.

The construction of the apparatus is shown in fig. 3,332. Steam from the sampling tube enters the calorimeter through pipe A, and is discharged downwards into the cup B. The course of the steam and water is here reversed, with the result that the water is thrown outward through perforations in the cup and collects in the inner chamber C, where it is measured by the gauge glass D.

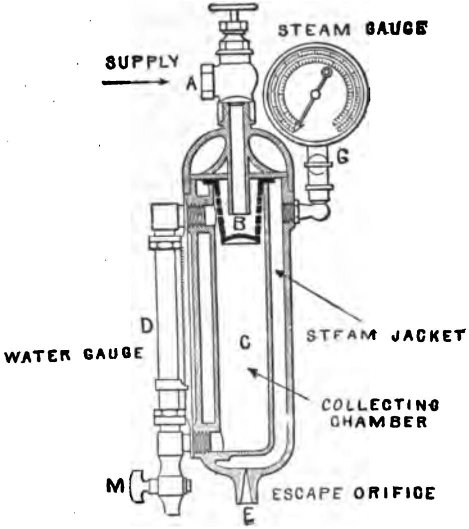
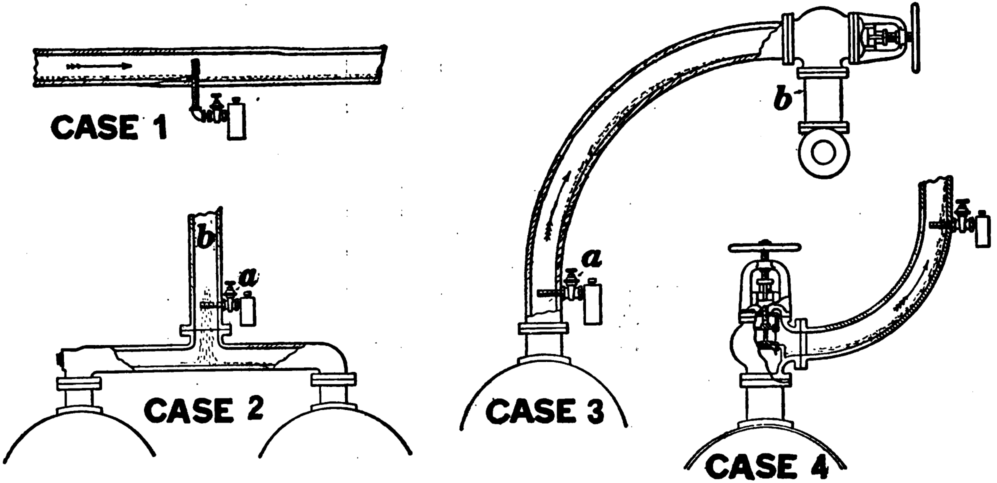


Fig. 3,332.—The separating calorimeter. Invented by Prof. Carpenter; it is used when the percentages of moisture in the steam is beyond the range of the throttling calorimeter. The calculations with this instrument are very simple, and tests show the steam discharged from it to be practically dry.

The steam passes upward and then downward into the outer chamber, whence it escapes through a standard orifice E, into the air. The apparatus is thus jacketed by the escaping steam, which is maintained at a high pressure by the throttling at E. A gauge at G, shows the pressure of the steam and the corresponding discharge in pounds per 10 minutes. The calculations with this instrument are very simple, and tests show the steam discharged from it to be practically dry.



FIGS. 3,333 to 3,336.—Connections which give erroneous calorimeter readings, illustrating improper location of sampling nozzle. *Case 1*, Horizontal pipe. Water flows at bottom. If perforations in nozzle be too near bottom of pipe, water piles against nozzle, flows into calorimeter and gives false reading. *Case 2*, If nozzle be located too near junction of two horizontal runs, as at *a*, condensation from vertical pipe which collects at this point will be thrown against the nozzle by the velocity of the steam, resulting in a false reading. Nozzle should be located far enough above junction to be removed from water kept in motion by the steam velocity, as at *b*. *Case 3*, Condensation in bend will be held by velocity of the steam as shown. When velocity is diminished during firing intervals and the like moisture flows back against nozzle, *a*, and false reading is obtained. A true reading will be obtained at *b*, provided condensation is not blown over on nozzle. *Case 4*, Where non-return valve is placed before a bend, condensation will collect on steam line side and water will be swept by steam velocity against nozzle and false readings result.

Example—If 12 pounds of steam be discharged through the orifice E, in 10 minutes, and the amount of water separated by the calorimeter is 11 ounces, what percentage of moisture does the steam contain?

Here, $W = 12$; $w = {}^{11}\!/_{16}$, substituting in the formula,

The height of the water in the glass D, at the beginning of the test is noted and marked by the gauge, and the water is again brought to the same level at the end of the test, by opening cock M, and the amount drained very carefully weighed. The results may be calculated by the following formula:

$$x = \frac{W}{W+w}$$

and the amount of moisture is

$$1-x$$

where

x = the quality of the steam, or dryness fraction;
W = weight of steam discharged through orifice E;
w = weight in pounds of separated water in C, drained through cock M.

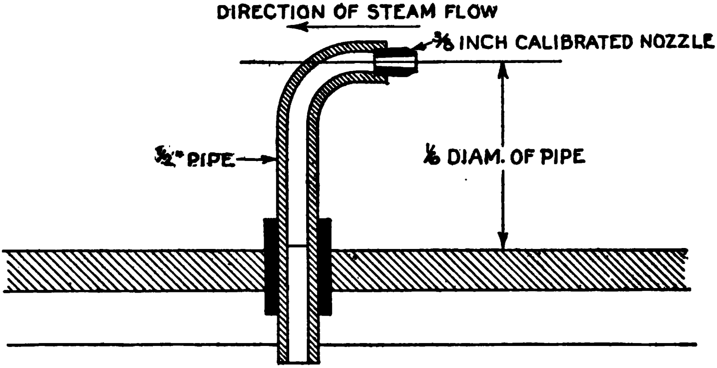


FIG. 3,337.—Stott and Pigott sampling nozzle. This was developed due to the lack of experimental data on low pressure steam quality determination. Mr. Pigott says: "The ordinary standard perforated pipe sampler is absolutely worthless in giving a true sample and it is vital that the sample be abstracted from the main without changing its direction or velocity until it is safely within the sample pipe and entirely isolated from the rest of the steam.

$$x = \frac{12}{12+\frac{11}{16}} = \frac{12}{12.687} = .9459$$

The moisture then is

$$1-.9459 = .0541 \text{ lb., or } 5.41 \text{ per cent.}$$

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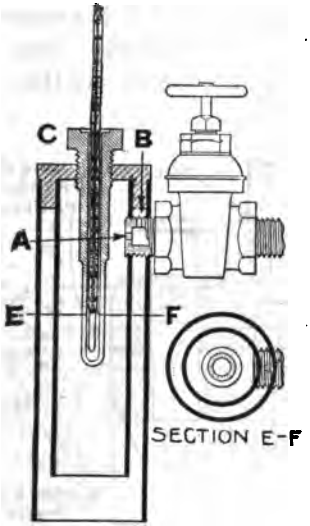
*NOTE.—In connecting a calorimeter, a sampling tube is used, through which a sample of the steam is taken from the main steam pipe. The usual form of tube is a ½-inch pipe extending nearly across the steam pipe, open at the inner end, and perforated with small holes. The quality of the sample of steam will depend somewhat upon the location of these holes. It is practically impossible according to Prof. Jacobus to obtain a true average sample of the steam flowing in a pipe.

Usual Amount of Moisture in Steam Escaping from a Boiler.—In the common forms of horizontal tubular stationary boilers, and water tube boilers with ample horizontal drums, supplied with water free from substances likely to cause foaming, the moisture in the steam usually does not exceed 2% when not worked above the rated capacity.



Horizontal tubular boilers without steam domes should be provided with a so called *dry pipe*, which will deliver steam with less moisture.

Vertical tubular boilers with through tubes will under normal conditions furnish steam with a slight degree of superheat, the tube portion above the water line acting as a superheater.

FIG. 3,330.—Compact form of throttling calorimeter. *It consists of* two concentric metal cylinders screwed to a cap containing a thermometer well. The steam pressure is measured by a gauge placed in the supply pipe or other convenient location. Steam passes through the orifice A, and expands to atmospheric pressure, its temperature at this pressure being measured by a thermometer placed in the cup C. To prevent as far as possible radiation losses, the annular space between the two cylinders is used as a jacket, steam being supplied to this space through the hole B. The limits of moisture within which the throttling calorimeter will work are, at sea level, from 2.88 per cent at 50 pounds gauge pressure and 7.17 per cent moisture at 250 pounds pressure.

NOTE.—"The throttling steam calorimeter, first described by Professor Peabody, in the *Transactions*, vol. x., page 327, and its modifications by Mr. Barrus, vol. xi., page 790; vol. xvii., page 617; and by Professor Carpenter, vol. xii., page 840; also the separating calorimeter designed by Professor Carpenter, vol. xvii., page 608; which instruments are used to determine the moisture existing in a small sample of steam taken from the steam pipe, give results, when properly handled, which may be accepted as accurate within .5 per cent (this percentage being computed on the total quantity of the steam) for the sample taken. The possible error of .5 per cent is the aggregate of the probable error of careful observation and of the errors due to inaccuracy of the pressure gauges and thermometers, to radiation, and, in the case of the throttling calorimeter, to the possible inaccuracy of the figure .48 for the specific heat of superheated steam, in the pipe from which the sample is taken. The practical impossibility of obtaining an accurate sample, especially when the percentage of moisture exceeds two or three per cent. is shown in the two papers by Professor Jacobus in *Transactions*, vol. xvi., pages 448, 1,017. In trials of the ordinary forms of horizontal shell and of water tube boilers, in which there is a large disengaging surface, when the water level is carried at least 10 inches below the level of the steam outlet and when the water is not of a character to cause foaming, and when in the case of water tube boilers the steam outlet is placed in the rear of the middle of the length of the water drum, the maximum quantity of moisture in the steam rarely, if ever, exceeds two per cent."—*Kent.*

Sampling Nozzle.—The principle source of error in steam calorimeter determinations is the failure to obtain an average sample of the steam delivered by the boiler and it is extremely doubtful whether such a sample is ever obtained. The two governing features in the obtaining of such a sample are the type of sampling nozzle used and its location.

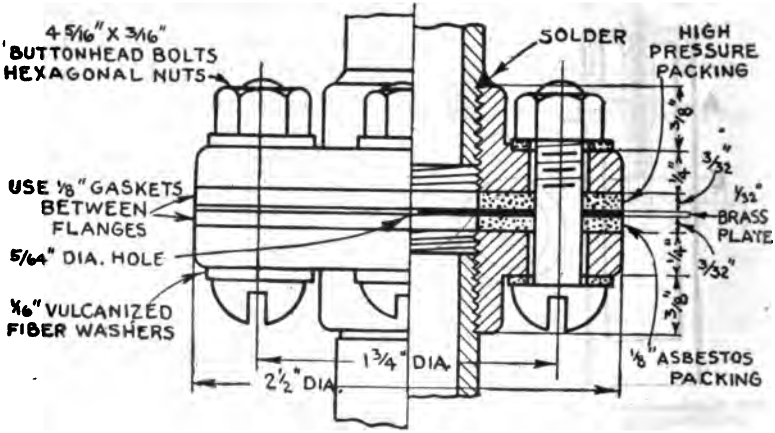


FIG. 3,339—Orifice plate for throttling calorimeter.

The American Society of Mechanical Engineers recommends a sampling nozzle made of one-half inch iron pipe closed at the inner end and the interior portion perforated with not less than twenty one-eighth inch holes equally distributed from end to end and preferably drilled in irregular or spiral rows, with the first hole not less than one-half inch from the wall of the pipe. Many engineers object to the use of a perforated sampling nipple because it ordinarily indicates a higher percentage of moisture than is actually present in the steam. This is due to the fact that if the perforations come close to the inner surface of the pipe, the moisture, which in many instances clings to this surface, will flow into the calorimeter and cause a large error. Where a perforated nipple is used, in general, it may be safe that the perforations should be at least one inch from the inner pipe surface.

A sampling nipple, open at the inner end and unperforated, undoubtedly gives as accurate a measure as can be obtained of the moisture in the steam passing that end. It would appear that a satisfactory method of obtaining an average sample of the steam would result from the use of an open end unperforated nipple passing through a stuffing box which would allow the end to be placed at any point across the diameter of the steam pipe.

CHAPTER 56

FUELS

By definition, the term ***fuel***, broadly speaking, is *any substance which, by its combination with oxygen evolves heat*. It is, however, generally applied, to those substances which are in common everyday use for heat producing purposes.

The many kinds of fuel used for the generation of steam may be classified:

1. With respect to character, as:

   a. Natural fuels;
   Such as wood, coal, crude petroleum and natural gas.

   b. Prepared fuels;
   Such as powdered coal and briquettes.

   c. By-products and end-products from industries;
   Such as bagasse, tan bark, blast furnace gas, coke oven gas, waste gases from cement kilns, open hearth furnaces, etc.

2. With respect to their *state*, as:

   a. Solid
   - **Coal**
   - **Coke**
   - **Peat**
   - **Tar**
   - **Wood**
   - **Tanbark**
   - **Sawdust**
   - **Bagasse**
   - **Tar, etc.**

NOTE.—The methods of firing the various fuels here mentioned are explained at length in later chapters.

b. Liquid

The various liquids of the petroleum group.

c. Gas $\left\{\begin{array}{l}\text{Natural gas.}\\\text{Producer gas.}\end{array}\right.$

Of the various fuels here tabulated, coal is by far the most extensively used. The use of wood is restricted to special and peculiar processes as the necessary and increasing demand for its use for structural and other industrial purposes has nearly removed it from any consideration as a fuel.

Special processes and favorable local conditions are necessary before any competition between either fuel oil or of gases and coal can exist.

A. SOLID FUELS

COAL

The dark brown or black mineral substance known as coal is a formation from plants that flourished ages ago, oxidation being prevented by the fact that they fell into swamps and morasses, and became covered with a protective layer of water. Afterwards they were entombed under billions of tons of sandstone, limestone and clay. The resulting pressure and heat caused the vegetable matter to assume the form of coal.

The store of energy was not reserved during the transformation period, this being evident from the fact that all plants will burn.

Ques. How do plants receive energy?

Ans. When a plant is exposed to sunlight it has the power of chemically combining water with a gas known as carbon monoxide (chemical symbol CO), the same gas that is given off by animals in breathing. While the plant is able to form the actual combination of gas and water, the sun does the actual work, using some of its energy in the operation.

The energy of the sun in helping the plant in its work of chemical combination, is just as much work and of practically the same kind as that put forth by a laborer in carrying a hod of bricks up a ladder, for as the energy expended by the laborer remains at the top of the ladder, so does the energy expended by the sun remain within the wood built up by the plant and the sun.

When the wood, or the equivalent, coal, is placed under proper conditions of sufficient heat and abundance of air supply, the wood returns to its original components, water and carbonic oxide gas, and the sun's energy that has been imprisoned within the wood or coal is set free in the form of heat.

Ques. What are the chemical constituents of coal?

Ans. Carbon, hydrogen, oxygen, nitrogen, and inorganic matter that constitutes the ash. Sulphur in the free state is sometimes present in coal.

Ques. Explain the terms volatile matter, fixed carbon, total combustible, and ash?

Ans. In the language of the chemist, that part of coal, moisture excepted, which is driven off when a sample is subjected to a temperature up to about 1,750° F. is the *volatile matter;* the solid carbon is the *fixed carbon;* the sum of volatile matter and fixed carbon is the *total combustible*, and the part that does not burn is *ash*.

Ques. What causes the different heating values of the mining grades of coal?

Ans. The varying quantities of the chemical constituents and their combinations.

Ques. Where is coal found?

Ans. It lies in horizontal or inclined layers, being separated by seams of clay and frequently mixed with iron compounds.

It is found in the geological formation commonly known as the carboniferous, and it generally lies between primary formations called *silurian*, or sand stone.

Classification of coal.—All coals as already explained are formed from prehistoric vegetable growths, fossilized by moisture, heat, pressure and time.*

These deposits vary considerably in age, and distinct species exist which may be distinguished from one another as well by the physical structure as by the chemical peculiarities.

The coal which occurs above the chalk formation is of comparatively recent origin. This is *lignite* or brown coal, which frequently contains almost the entire structure of the vegetable matter from which it was formed.

That lying below the chalk is known as *bituminous* coal and in it the vegetable feature has disappeared excepting in isolated cases. Both differ from the *anthracite* or oldest coal, from which almost everything has disappeared excepting the carbon. The approximate chemical and structural changes which have taken place are tabulated according to age as follows:

Substance	*Carbon*	*Hydrogen*	*Oxygen*
Wood fibre	52-53%	5-55%	40-42%
Peat	58-60%	55-60%	40-42%
Lignite	60-62%	50-55%	34-35%
Brown coal	65-70%	50-55%	25-30%
Bituminous coal	70-85%	55-60%	18-20%
Anthracite coal	85-92%	4-57%	4- 4½ %

Ques. Which is the youngest coal?

Ans. Lignite.

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*NOTE.—As evidence of the vegetable origin of coal, fossilized trees are found standing upright and with their roots resting in the seams of coal, also ferns, leaves boughs, etc., either wholly or partially fossilized are found in peat bogs. It is stated that several hundred different species of plant life have been identified in and among coal formations. These evidences found in the coal measures, by the comparison with existing forms of plant life, testify to the fact that the climate now existing at those points is materially changed from that which existed at the time of their growth. All such specimens which have been found indicate that their natural habitat was in a very warm, moist climate, and that after falling were subjected to various changes of location due to internal disturbances of the earth, at times being buried under the water, and at other times, probably by volcanic action, elevated high above the water.

Ques. Which is the oldest coal?

Ans. Anthracite.

A classification of the great variety of coal, to be comprehensive, should be made from several points of view, as:

1. With respect to density, as
   - *a*. Soft or so-called bituminous coal
   - *b*. Hard or anthracite coal
2. With respect to age, as:
   - *a*. Lignite
   - *b*. Bituminous
   - *c*. Semi-bituminous
   - *d*. Semi-anthracite
   - *e*. Anthracite
3. With respect to the characteristics of combustion:
   - *a*. Caking or non-caking
   - *b*. Long or short flaming
   - *c*. White or red ash

Anthracite Coal.—This is said to be the oldest and deepest formation, and is found principally in the United States. It is also found in the western part of the South Wales coal fields; in the neighborhood of Swansea; in some parts of Scotland; to a small extent in France; in the South of Russia; and in the Osnabrück district of Westphalia, Germany.

Anthracite coal represents the highest quality of fuel known; that is, it is the nearest approach to pure carbon combustible. Because of difficulty in kindling, this coal for years was considered too nearly like a rock to be burned. It was first used in 1766 for blacksmith work and shortly afterward came into considerable use for metallurgical processes, but even as late as 1812, it was unknown for any large use under boilers.

Today the enormous demand for anthracite coal threatens its extinction within a few years.

Semi-Anthracite Coal.—In its physical characteristics and appearance

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*NOTE.—***Bituminous** is of Latin origin, meaning *containing or resembling bitumen*. Bituminous coals contain no bitumen, the name having been applied because of a misconception of their nature, due to the resinous feel of certain kinds. ***Anthracite*** is a word of Greek origin, meaning *carbon* or *coke*, the fuel being so named probably because it is that which contains the largest percentage of fixed carbon.

it closely resembles anthracite. It is represented by what is known as Welsh anthracite, and by coals from a limited territory in Pennsylvania.

Semi-anthracite coals break with a conchoidal fracture and have a lustrous surface. They kindle with difficulty, are low in volatile and high in fixed carbon, but have more ash than the anthracites and somewhat more oxygen. When handled they soil the hands slightly, and are not of great importance for power plant use because of the high cost and small supply.

Semi-Bituminous Coal.—Represented chiefly by the Cardiff or Welsh coals from the enormous fields of South Wales and in the U. S. by the rich deposits on the slope of the Appalachian Mountains, extending from Clearfield County, Pa., to the southern boundary of Virginia, the coals in this belt taking the names of Pocahontas, George's Creek, Clearfield, etc. The Belgian coal, known as Demigras, is also of this class.

Semi-bituminous coals are among the finest of fuels for steam making, as they give a high heat value with less difficulty in avoiding smoke than bituminous coals. In appearance and action they are more like the anthracites than the bituminous coals, but contain more volatile matter than the anthracites. The better grades, however, are almost free from smoke and are easier to kindle than the anthracites. The supply of these coals is small and the resulting high price limits their use for boilers.

Bituminous Coal.—This kind of coal is found almost all over the world. The largest known fields are in Scotland, England and the U. S. Most bituminous coals are a dense black, but in some cases vary toward a brown. The luster is resinous.

The best quality coals are soft and silky to the feel. Caking and non-caking varieties have distinctly different characteristics. The non-caking coals are more like lignites, rather hard and brittle and will not melt nor fuse together in the furnace or when caked. They burn with a yellow smoky flame and are good for gas producers. Caking coals when thrown into the furnace swell and fuse into a mass which must be broken up occasionally to allow the fire to get through it. These are, however, rich in volatile matter and burn with a long yellow smoky flame which makes it difficult to avoid making smoke when using them, particularly after green coal has been thrown on the fire.

Because of the wide variation in the composition of bituminous coals, the furnace should be adapted to a particular variety to get the best results.

With bituminous coals not only must the furnace be properly designed, but the firing should be properly done to secure smokeless and efficient combustion.

Cannel Coal.—This variety of bituminous coal is found in the Midlands of England, and in the U. S. It is used principally for making illuminating gas and for domestic purposes. It is a variety of bituminous coal very rich in hydrogen.

In appearance this coal differs from all others. Its structure is more nearly uniform than others, being a compact mass, varying from brown to black in color, and having usually a dull resinous luster. When broken it does not usually preserve any distinct order of fracture, and is liable to split in any direction.

Being very rich in hydrocarbons it is well adapted for gas producers, the preference being in those coals in which hydrogen bears the greatest proportion to the contained oxygen. It readily kindles and burns without melting, emitting a bright flame like that of a candle, and produces a crackling noise in splitting up into fragments when thrown on the fire.

Block Coal.—The peculiarity of this formation from which it derives its name is the presence of fractures occuring in the coal bed at right angles or nearly so, and extending from top to bottom of the seam, enabling the miner to get it out in rectangular blocks.

It is a non-caking bituminous coal occurring in large quantities in Indiana. It burns well under a heavy load without caking.

The coal is of a dull lusterless black, in thin laminæ, separated by fibrous charcoal partings, very strong across the bedding lines, and is free from pyrites and calcite. It is largely used for boilers, domestic stoves, grates and also for blast and puddling furnaces.

Lignite.—The principal lignite fields are in France, Italy, Germany and Austria, but lignite is also found in the U. S. and in Sweden.

As found in the mines, lignite varies from a brown to a deep black, according to its composition, the poorer grades carrying the earthy brown color and the better grades the black approaching that of bituminous coals. There are indications of the organic structure in the lower grades.

Lignites are easily ignited because of the softness in texture and high percentages of hydrogen and oxygen. They burn with a flame somewhat resembling peat. Lignites absorb water easily, and carry a high percentage of moisture which cuts down their heating value.

The ash will run from 9 to 58% and with a lignite which is high both in ash and moisture, the heating value may be so low as to make it undesirable for boilers.

Lignites are non-caking and hardly more like anthracite than like bituminous coals.

A thick fire and strong draught must be carried because of the low heating value. Lignites are brittle and usually break up when thrown on the fire. They are also likely to break up when left exposed to the weather.

Culm.—Formerly this was waste product and had no commercial value. It is fine anthracite coal. Culm banks abound in the anthracite regions of Pennsylvania and consist of mixed fine coal of many sizes, with a considerable proportion of slate and pyrites, requiring careful attention as to draught, firing and details of grate upon which it is to be burned.

Heating Values of Coal.—The theoretical heating value of fuel is the heat which it develops when consumed under theoretically correct conditions—which are practically only obtained in the laboratory—and it is expressed in heat units or thermal units. In England and the United States the British thermal unit is adopted; on the Continent of Europe the "calorie" is used.

The theoretical heating value of coals varies from about 7,000 to 15,500 *B.t.u.* per pound, depending largely on the varying amount of uncombustible matter or ash that the coals contain.

The semi-bituminous coals of the Pocahontas and Cardiff varieties are the most nearly uniform in this respect, the ash being only 3 to 8 per cent.; Belgian "Demigras" will run from 5 to 15 per cent., while the residue in Transvaal coal may reach 25 to 35 per cent.

The anthracite coals, as mined, contain from 15 to 30 per cent. of refuse or slate. Most of this, however, is usually removed when the coal is prepared for the market, so that anthracite, as sold, may contain as little as 3 per cent. On the other hand, the smaller sizes may run very high in ash, and cases have been known where 50 per cent. refuse has been found in boiler tests.

Bituminous coals are extremely variable, running from 5 to 35 per cent. ash, while the percentage in lignite is usually considerably under 10.

The heating value of the combustible portion of the coal (ash and moisture deducted) is also quite variable, and depends on the quality of the volatile matter, which may be either very rich in hydrocarbons, as in semi-bituminous coals, or comparatively high in oxygen, as in many of the bituminous coals and lignite. So much, in fact, does the amount of oxygen found in lignite detract from the heating value of the volatile matter, that the combustible portion of lignite is worth only about three-fourths that of semi-bituminous coal.

The following table gives a classification of American coals according to the heating values, being the table prepared by Kent (*Journal A. S. M. E.*, vol. 36, p. 437, 1917) but arranged in the order of ascending heating values.

Classification of American Coals

Class	Volatile matter in % of combustible	Oxygen in combustible %	*B.t.u.* per pounds of combustible
Sub-bituminous and lignite...	27 to 60	10 to 33	9,600 to 13,250
Bituminous, low grade.......	32 to 50	7 to 14	12,400 to 14,600
Bituminous, medium grade...	32 to 50	6 to 14	13,800 to 15,100
Anthracite..................	less than 10	1 to 4	14,800 to 15,400
Semi-anthracite.............	10 to 15	1 to 5	15,400 to 15,500
Bituminous, high grade......	30 to 45	5 to 14	14,800 to 15,600
Semi-bituminous............	15 to 30	1 to 6	15,400 to 16,050
Eastern cannel..............	45 to 60	5 to 8	15,700 to 16,200

The United States Geological Survey has gone into the matter of proper grouping or classification of coals very exhaustively. In the report on the coal testing plant at St. Louis, using various elements and ratios, they found that the carbon hydrogen ratio $\frac{C}{H}$, while not perfect, seems to fit the cases better than any others, and suggest for investigation and discussion the following groups, arbitrarily designated by letters:

Group	A (Graphite)..............	8 to (?)
"	B Anthracite...............	(?) to 30 (?)
"	C "	30 (?) to 26 (?)
"	D Semi-Anthracite........	26 (?) to 23 (?)
"	E " Bituminous........	23 (?) to 20 (?)
"	F Bituminous..............	20 to 17
"	G "	17 to 14.4
"	H "	14.4 to 12.5
"	I "	12.5 to 11.2
"	J Lignite..................	11.2 to 9.3 (?)
"	K Peat.....................	9.3 (?) to (?)
"	L Wood....................	7.2

From this report is here quoted the following:

Groups A, B, C, D, and E. As little work was done at this testing plant on anthracite coal, and as all of the analyses made by the Second Geological Survey of Pennsylvania were proximate analyses, little material is available for determining the limits of these groups and the figures given must be regarded as provisional only, and subject to change when a greater number of ultimate analyses have been made.

Groups F, G. H, I.—These groups embrace what generally are considered bituminous coals.

Group F.—Includes Pocahontas coal, the high grade Arkansas coals west of the Spadra District and New River coals.

Group G.—Includes upper Freeport and Pittsburg coals or Northern W. Virginia, Kanawha Valley coals, high grade Kentucky coals, and Alabama coals.

Group H.—Includes all Indian Territory coals, all Kansas coals, high grade Illinois, Iowa and Missouri coals, and second grade Kentucky coals.

Group I.—Includes the great majority of Iowa, Illinois, and Missouri coals, Indiana coal and some bituminous coals from Wyoming and Montana.

Group J.—Includes all the lignites, both black and brown that were tested.

Group K.—Is limited to peat and is based entirely upon one analysis obtained from outside sources.

Group L.—Is woods, the lowest group in the series.

Coal from every district, indeed from different mines of the same region vary in their composition. Any table of analyses could therefore only be of very restricted use, since it is of course impracticable to publish a complete list.

Sizes of Coal.—As taken from the mine, coal varies in size from lumps to a fine dust.

Ques. What is the effect of size of lumps on coal?

Ans. In general the smaller the size the greater is the amount of impurities present, the heat value is lower, more coal sifts through the grate, and other objectionable results are increased. As a consequence, the larger sizes usually command higher prices, especially for anthracite.

Ques. How is coal graded into sizes?

Ans. By screening through standard openings which, however, differ somewhat both as to size and shape in different localities.

The preliminary report of the Committee on Power Tests of the American Society of Mechanical Engineers (1912) recommends the grading of coal as follows:

Sizes of Anthracite Coal

Size	Diameter of opening through or over which coal will pass, inches	
	Through	Over
Broken	4½	3¼
Egg	3¼	2 5/16
Stove	2 5/16	1⅝
Chestnut	1⅝	⅞
Pea	⅞	9/16
No. 1 Buckwheat	9/16	5/16
No. 2 Buckwheat	5/16	3/16
No. 3 Buckwheat	3/16	3/32
Culm	3/32	...

Sizes of Bituminous Coal—Eastern States

Run of mine coal.—The unscreened coal taken from the mine.

Lump coal—That which passes over a bar screen with openings 1¼ inches wide.

Nut coal.—That which passes through a bar screen with 1¼-inch openings and over one with ¾-inch openings.

Slack coal.—That which passes through a bar screen with ¾-inch openings.

Sizes of Bituminous Coal—Western States

Run of mine coal—The unscreened coal taken from mine.

Lump coal—Divided into 6-inch, 3-inch and 1¼-inch lump according to the diameter of the circular openings over which the respective grades pass; also into 6×3 lump and 3×1¼ lump according as the coal passes through a circular opening of the larger diameter and over one of the smaller diameter.

Nut coal—Divided into 3-inch steam nut, which passes through a 3-inch circular opening and over a 1¼-inch; 1¼-inch nut, which passes through a 1¼-inch circular opening and over a ¾-inch; and ¾-inch nut, which passes through a ¾-inch circular opening and over a ⅝-inch.

Screenings.—That which passes through a 1¼-inch opening.

Bituminous and semi-bituminous coals usually crumble to powder when handled, particularly if left exposed to the open air for a time, as they absorb moisture rapidly and this moisture will not be driven off except by heating the coal up to 250° F. Such coals are therefore sold as *run of mine*, which means that lumps and dust and all sizes between are sold in one mass.

COKE

Ques. What is coke?

Ans. The solid substance remaining after the partial burning of coal in an oven or after distillation in a retort.

When the former process is used, the coke is the primary product, and any other products are considered as by-products, being quite frequently thrown away, although modern coke making processes save most of them.

In the retort process, however, the coke itself is one of the by-products, the gases being the object of the operation, although the by-products have in later years become better revenue producers than the gas itself.

Ques. How is gas retort coke produced?

Ans. It is produced by the application of high temperatures to the outside of the retort for a short time.

The product is soft, spongy, and of dark grey color, approaching black. It is not fitted for metallurgical work, and its principal use is for domestic purposes, and in steam boiler practice.

Coke produced in beehive ovens, however, is made under lower temperatures, the process requiring from 48 to 72 hours. It is hard, dense, and of a light grey color, has a brilliant metallic lustre, and will ring when struck. The product is especially adapted for heavy metallurgical work, but its high cost precludes its use for either steam boilers or domestic purposes. This same grade of coke is now extensively produced in closed ovens in a very much more economical way.

Ques. Does chemical analysis show much difference in the heating value of different cokes?

Ans. It shows very little difference.

The heating value is roughly considered as being about 14,000 *B.t.u.* per pound, and the difference in adaptability is due to the physical differences. Analyses of twenty-nine samples of coke from six different states give averages as follows:

Carbon 89.15%; Sulphur .918%, Ash 9.21%

The average weight of solid coke may be taken as 45 pounds per cubic foot. The average weight of heaped coke may be taken as 30 pounds per cubic foot. One long ton heaped averages 75 cubic feet.

Under ordinary conditions coke carries from 5% to 10% water, and if unprotected, will absorb from 15% to 25% of its own weight.

Good coal carefully handled in a beehive oven produces on an average of about 66% to 66½% coke, which can be marketed as such; about 2% to 2½% of breeze or fine coke, and from .75% to 1% ash, there being an average of about 30% to 31% loss, mostly due to the volatile matters driven off in the coking process.

PEAT

Ques. What is peat?

Ans. A substance of vegetable origin always found more or less saturated with water in swamps and bogs.

It consists of roots and fibres in every stage of decomposition, from the natural wood to vegetable mold. It is valuable as a fuel only after having been dried out as much as possible. As found in the bog, peat usually contains 85% to 90% of water, and when air dried still holds at least 15% moisture.

Ques. What does an analysis of air dried peat of good quality show?

Ans. About 48% carbon, 4% hydrogen, 27% oxygen, 1% nitrogen. 15% moisture, 5% ash. 9,000 *B.t.u.*

The analysis of perfectly dried peat would be about as follows:

58% to 60% carbon, 6% hydrogen, 30% to 31% oxygen, 1%to 1½% nitrogen, 2¾% to 5% ash. 10,260 *B.t.u.*

Ques. What is the weight of peat per cubic foot?

Ans. Heaped, it is from 6 pounds to 22½ pounds, or 33.3 cubic feet to 88.8 cubic feet per ton of 2,000 pounds.

Ques. How is peat prepared as a fuel?

Ans. It is prepared in three forms: 1, as hand or spade peat; 2, as briquetted peat: 3, as machine peat.

1. Spade peat is obtained by cutting out of the bog regularly shaped blocks, stacking the blocks on the ground to dry. The product is very commonly friable, will not stand transportation, is not suitable for coking and is usually quite bulky, although the specific gravity may run from 2 to 1.3.

2. Briquetted peat is produced by compressing dry powdered peat with heavy machinery into regularly shaped blocks. The briquetted fuel is clean, and bears transportation fairly well.

3. Machine peat is prepared on the principle that when raw peat containing from 80 to 85% of water is thoroughly mixed and kneaded, it loses its fibrous structure and on drying, shrinks firmly together into a compact mass of about one-fifth the original volume.

WOOD

The term wood is generally used to designate the limbs and trunks of trees as they are felled.

NOTE.—Peat is found in many parts of Europe, and has been used in Ireland for many years as a domestic fuel. A very valuable deposit exists in Minnesota, where hundreds of acres of peat several feet deep have been found.

Woods may be divided into two classes: 1. Hard, compact and comparatively heavy woods, such as oak, beech, elm and ash. 2. The light-colored, soft, and comparatively light woods, such as pine, birch, poplar and willow. When freshly cut, about 45% of the total weight of wood is water, and when air dried and kept in a dry location, it still retains from 15% to 25% of water.

Ques. What is the relative heating value of wood as compared with coal?

Ans. The heating value of thoroughly dried wood is about 40% of that of coal.

Ques. What is the effect of water in wood?

Ans. It causes a loss of economy.

This is shown in the following table, which gives the difference in chemical composition and heat value between perfectly dried wood and ordinary fire wood:

	Dry wood.	Ordinary fire wood.
Carbon	50%	37.5%
Hydrogen	6%	4.5%
Oxygen	41%	30.75%
Nitrogen	1%	0.75%
Ash	2%	1.50%
	100%	75.00%
Moisture		25.00%
Total		100.00%

The heat values of the above are as follows:

	7,840 *B.t.u.*	5,880 *B.t.u.*
Equivalent to	8.1 lbs. of water	6.1 lbs. of water

evaporated per pound of fuel from and at 212° F. theoretically.

From the above it will be seen that there is a loss of heating power per pound of ordinary fire wood of 25%, due to the presence of the hydrometric water, and there is a still further loss of 5% due to the fact that this water must be evaporated.

NOTE.—Suppose the wood with its contained water to be fed onto the fire at the ordinary temperature of 62° F. Each pound of water therefore will require about 1,116.6 *B.t.u.* to heat it up to 212° F. and evaporate it at this temperature, and as each pound of wood by above analysis contains ¼ pound of water, this will require 279 heat units to evaporate it, which is 4.7 per cent of the total heat generated, so that ordinary fire wood has only about 71 per cent of the heat value of perfectly dry wood. The A. S. M. E. have established a value of wood in its equivalent in coal for the purpose of boiler testing as above stated, viz: 1 pound of wood = .4 pounds of coal, but in case greater accuracy be desired 1 pound of wood may be considered as having a heating value equivalent to the evaporation of 6 pounds of water *from and at* 212° *F.*, which is equivalent to 5,794 *B.t.u.* per pound.

TAN BARK

Tan bark, usually oak bark after having been used in the process of tanning, is frequently burned as fuel. The spent bark consists of the fibrous portions, and according to M. Peclet, five parts of oak bark produce four parts of dry tan the heat value of which is about 6,100 *B.t.u.*, and this so called dry tan contains about 15% of ash.

Tan bark in its ordinary state of dryness contains about 30% water and has a heating value of 4,284 *B.t.u.* The theoretical evaporation *from and at 212° F.*, of 1 pound of spent bark (equivalent to the heating value just given) is about 4.12 pounds of water.

Ques. How is wet tan bark burned successfully?

Ans. By burning it in a furnace of sufficient volume to accommodate a large quantity of wet bark, exposed to the heated gases coming from the burning bark, which has been previously dried.

As the wet bark becomes dried, it must be fed down and burned, where its hot gases in turn assist in drying the newly fed fuel. The rate of combustion is limited by the rapidity of the drying process. If it exceed this, the dry portion burns up, leaving the wet fuel which will not burn.

STRAW

Straw consists of the stems or stalks of grain, and its principle use is for plaiting, thatching, paper making, etc., but in certain localities it is used as a fuel.

Ques. What is the heating value of straw?

Ans. Tests of wheat and barley straw give average of 5,411 *B.t.u.*, out of which 153 *B.t.u.* must be used in evaporating the natural water, leaving 5,258 *B.t.u.* available, which is equivalent to the evaporation of 5.4 pounds of water per pound of straw *from and at 212° F.*

SAWDUST

The conditions necessary for burning sawdust are that ample room should be given it in the furnace and sufficient air supplied on the surface of the mass; the same applies to shavings, refuse, lumber, etc.

Ques. What is the heating value of sawdust?

Ans. It is naturally the same as that of the wood from which it is derived, but if allowed to get wet, it is more like spent tan.

Mr. W. S. Hutton gives the following heating values of combustible refuse:

	B.t.u. per lb. of fuel.
Oak bark, dry	6,279
Oak bark, in a damp state	3,024
Sawdust from oak or other hard woods, dry	5,912
Sawdust from pine or other soft woods, dry	5,217
Sawdust in moderately dry state, averages	3,961
Wood chips and sawdust, mixed, moderately dry, averages	3,671
Wood chips and green twigs in a damp state, or containing 50 per cent. of moisture, average	1,932

BAGASSE

Ques. What is bagasse?

Ans. The fibrous portion of sugar cane left after the juice has been extracted.

It consists of woody fibre, water, sucrose, glucose and other solids in varying proportions, depending upon the quality of the cane and its treatment in the mill.

Ques. What is its heating value?

Ans. Its average heating value when dry is 8,360 *B.t.u.*

TAR

Coal Tar.—The value of coal tar as a fuel is usually very much lower than its value for other purposes, but it is at times used to advantage as a fuel. The yield of coal tar varies with the kind of coal and with the methods employed, from about 4½ to 6½% of the weight of coal.

It is lower in hydrogen and higher in carbon than crude oil, and therefore, of a lower calorific value. Tar made from standard gas coal would have an ultimate analysis about as follows:

Carbon	89.21%	Nitrogen	1.05%	Sulphur	0.56%
Hydrogen	4.95%	Oxygen	4.23%	Ash	trace

It has a specific gravity of about 1.25; a gallon weighing 10.3 pounds.

Using Dulong's formula as adopted by the A. S. M. E., such fuel would have about 15,800 *B.t.u.* per pound, and a theoretical evaporative power of about 16.4 pounds of water, from and at 212° F. A series of calorimetric tests give about 15,700 *B.t.u.* Coal tar may be burned if heated and strained, the same as other liquid fuels.

NOTE.—The following are some of the conclusions reached in Louisiana Bulletin No. 117: "Less excess of air is required with bagasse than with coal, usually 50% or less is sufficient. The rate of combustion should be at least 100 pounds per square foot of grate surface per hour, and best results were obtained with rates even higher than this. Not less than 1.5 boiler horse power should be provided per ton of cane per 24 hours. A good working furnace depends more upon the proportion of heating surface to the grate surface, rate of combustion and other matters of design and operation than upon the type or form. On account of the large amount of moisture in bagasse which is converted into steam in the furnace, a volume of gas and steam much larger than for coal must be provided for in the cumbustion chamber and the passages to the stack."

Oil Tar.—This is produced in an ordinary gas apparatus, has a specific gravity of 1.15, is less sticky than coal tar, and can be transported, handled and burned like other oils. Its analysis is about as follows:

Carbon	92.7 %	Nitrogen	.11%	Sulphur	.37%
Hydrogen	6.13%	Oxygen	.69%	Ash	trace

By the Dulong formula the above analysis would give 17,296 *B.t.u.*, and its theoretical evaporative power would be about 17.9 pounds of water from and at 212° F. By the calorimeter such oil gives a value of 17,190 *B.t.u.*

B. LIQUID FUELS

The many advantages of liquid fuel or fuel oil for use with steam boilers have been apparent for a long time, and, in localities where the crude oil or refuse from distillation could be obtained cheaply (or where coal is very expensive) it has been used with much satisfaction.

Petroleum is practically the only liquid fuel sufficiently abundant and cheap to be used for the generation of steam. It possesses many advantages over coal and is extensively used in many localities.

There are three kinds of petroleum in use, namely those yielding on distillation: 1st, paraffin; 2nd, asphalt; 3rd, olefine. To the first group belong the oils of the Appalachian Range and the Middle West of the United States. These are a dark brown in color with a greenish tinge. Upon their distillation such a variety of valuable light oils are obtained that their use as fuel is prohibitive because of price.

To the second group belong the oils found in Texas and California. These vary in color from a reddish brown to a jet black and are used very largely as fuel.

The third group comprises the oils from Russia, which, like the second, are used largely for fuel purposes.

Ques. In general, of what does crude oil consist?

Ans. It consists of carbon and hydrogen, though it also contains varying quantities of moisture, sulphur, nitrogen, arsenic, phosphorous and silt.

The moisture contained may vary from less than 1 to over 30 per cent, depending upon the care taken to separate the water from the oil in pumping from the well. As in any fuel, this moisture affects the available heat of the oil, and in contracting for the purchase of fuel of this nature it is well to limit the per cent of moisture it may contain. A large portion of any contained moisture can be separated by settling and for best results, sufficient storage capacity should be supplied to provide time for such action.

Ques. What is the heating value of petroleum?

Ans. A pound of petroleum usually has a calorific value of from 18,000 to 22,000 *B.t.u.*

Ques. What are the relative values of oil and coal as fuels?

Ans. Under favorable conditions 1 pound of oil will evaporate from 14 to 16 pounds of water *from and at 212 deg.;* 1 pound of coal will evaporate from 7 to 10 pounds of water *from and at 212 deg.*

The following tables show the comparison in more detail:

Relative Heating Values in Coal and Oil

	B.t.u. per pound
Petroleum residuum	19,500
Beaumont crude	18,500
Anthracite coal—East Middle coal field	13,400
Semi-bituminous—Cumberland, Maryland	14,400
Pocahontas, Virginia	15,070
Bituminous—Jackson County, Ohio	13,090
Hocking Valley, Ohio	12,130
Missouri coal	12,230
Alabama coal	13,500
McAllester coal, I. T.	12,789
New Mexico	12,000
Texas Lignite	10,000

These calorimeter values are carefully selected averages and furnish a means of comparing the different coals one with another, but in comparing liquid fuels with the solid, such as oil with coal, they do not form an accurate measurement of the relative value of the two kinds of fuel as steam makers, owing to incomplete combustion due to inefficient firing and other causes.

Comparative Evaporation of Coal and Oil

Taken from the United States Geographical Report on Petroleum

One Pound of Combustible	Pounds of Water Evaporat's at 212 deg. per pound of combustible	Barrels of Petroleum required to do same amount of evaporation as one ton of coal
Petroleum 18 to 40 deg. Baume.....		
Pittsburg lump and nut, Penna.....	10.	4.
Pittsburg nut and slack, Penna......	8.	3.2
Anthracite, Penna.................	9.8	3.9
Indiana block.....................	9.5	3.8
Georges Creek lump, Maryland.....	10.	4.
New River, West Virginia..........	9.7	3.8
Pocahontas lump, West Virginia.....	10.5	4.2
Cardiff lump, Wales...............	10.	4.
Cape Breton, Canada..............	9.2	3.7
Nanaimo, British Columbia.........	7.3	2.9
Co-operative, British Columbia.....	8.9	3.6
Greta, Washington................	7.6	3.
Carbon Hill, Washington...........	7.6	3.

The U. S. Naval Liquid Fuel Board appointed for the purpose of thoroughly investigating the problem of using oil as a boiler fuel, made an exhaustive report to the Navy Department. Their conclusions are given in full and while relating particularly to marine practice, there is much that is applicable to land practice.

NOTE.—The light and easily ignited constituents of petroleum, such as naphtha, gasoline and kerosene, are oftentimes driven off by a partial distillation, these products being of greater value for other purposes than for use as fuel. This partial distillation does not decrease the value of petroleum as a fuel; in fact, the residuum known in trade as "fuel oil" has a slightly higher calorific value than petroleum, and because of its higher flash point it may be more safely handled. Statements made with reference to petroleum apply as well to fuel oil.

Conclusions of the U. S. Naval Liquid Fuel Board.

a. Oil can be burned in a nearly uniform manner.

b. The evaporative efficiency of nearly every kind of oil per pound of combustible is probably the same. While the crude oil may be rich in hydrocarbons, it also contains sulphur, so that, after refining, the distilled oil has probably the same calorific value as the crude product.

c. A marine steam generator can be forced to even as high a degree with oil as with coal.

d. Up to the present time no ill effects have been shown upon the boiler.

e. The firemen are disposed to favor oil, and therefore no impediment will be met in this respect.

f. The air requisite for combustion should be heated if possible before entering the furnace. Such action undoubtedly assists the gasification of the oil product.

g. The oil should be heated, so that it can be atomized more readily.

C. GASEOUS FUEL

The gaseous fuels used in all steam boilers are natural gas, waste gas from blast furnaces, coke oven gas and producer gas. Natural gas, like mineral oil, is chiefly a mixture of hydrocarbons, but no great complexity exists, as few are gaseous at ordinary temperatures.

Natural gases contain varying amounts of CO, CO_2 and nitrogen, formed probably from the action of oxygen on the carbon, the nitrogen accompanying the oxygen. Blast furnace and producer gases contain large percentages of nitrogen and carbon dioxide, while coke oven gas contains much more combustible.

Ques. How do gas fuels compare with liquid fuels?

Ans. Gas fuels offer all the advantages of liquid fuels, and but few of the disadvantages.

Ques. What is the heating value of natural gas?

Ans. It varies from 800 to 1,100 *B.t.u.* per cubic foot.

1,000 cubic feet of natural gas is approximately equivalent to 57.25 pounds of coal.

Gaseous fuel has so many apparent advantages over any other that it may properly be regarded as the ideal fuel. Manufacturers who have once realized its advantages, would gladly welcome some kind of gaseous fuel, provided this can be made cheap enough to compete with the local coal.*

The following table shows the relative heat values of a few gases, and a comparison of each with soft coal:

Comparison of Gas and Coal.

Variety	Heat Units per 1000 cu. ft.	Equivalent pounds of coal.	Corresponding price per 1000 cu. ft.
Natural Gas.............	1,100,000	81.5	8.15 Cents
Coal Gas................	755,000	55.9	5.59 "
Water Gas...............	350,000	25.9	2.59 "
Producer Gas............	155,000	11.48	1.148 "

The coal is assumed to cost $2.00 per ton and to have a heat value of 13,500 *B.t.u.* The efficiency of the two fuels is assumed to be the same when burned under a boiler.

The last column shows what price should be paid for the gas in order to make it economical to use that fuel.

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*NOTE.—To answer this demand a number of processes have been invented. The U. S. Geological Survey in its report on the Mineral Resources of the United States, reports the production of natural gas in twenty-two states. In some of these states such quantities are produced that immense industrial operations are based on its use.

No account has been taken of the saving resulting from the less attention needed, the probably higher efficiency, the fact that there are no ashes to remove, and the greater ease of handling when gas is used.

These factors would make it possible to pay a higher rate for gas depending on the size of plant and the relative importance of the various items mentioned.

Cubic Feet of Gas Required per Horse Power Hour

Variety.	100 per cent efficiency.	80 per cent efficiency.	70 per cent efficiency.	60 per cent efficiency.
Natural Gas.......	30.4	38.0	43 5	50.7
Coal Gas..........	44.4	55.5	63.6	74.0
Water Gas........	95.6	119.5	136.5	159.2
Producer Gas.....	216.0	270.0	308.6	360.0

Water Evaporation on Basis of 75 Per Cent. Boiler Efficiency.

	Natural Gas.	Coal Gas.	Water Gas.	Producer Gas.
Pounds water from and at 212°F. per 1000 cu. ft. Gas.	851	584	270.5	120

CHAPTER 57

COMBUSTION

Ques. What is combustion?

Ans. *Rapid oxidation.*

It may further be defined as the rapid chemical combination of oxygen with any material which is capable of oxidation, the process being accompanied by the diffusion of heat and light

Ques. What is the oxygen called?

Ans. The supporter of combustion.

Ques. Where is it obtained?

Ans. In the air.

Pure air is a mechanical mixture of oxygen and nitrogen. The accepted values for the proportion of oxygen and nitrogen are: ***by volume,*** oxygen 20.91%, nitrogen 79.09%; ***by weight,*** oxygen 23.15%, nitrogen 76.85%.

Air in nature always contains other constituents in varying amounts, such as dust, carbon dioxide, ozone and water vapor. Being perfectly elastic, the density or weight per unit volume decreases in geometric progression with the altitude. This fact has a direct bearing in the proportioning of furnaces, flues and stacks at high altitudes. In nature the oxygen in the air is constantly causing slow combustion, thus iron rusts, various substances decay, etc.

Ques. What is the material called which is capable of combustion?

Ans. The combustible.

As used in steam engineering practice, however, the term combustible is applied to that portion of the material which is dry and free from ash, thus including oxygen and nitrogen, which may be constituents of the fuel, material; though not in the true sense of the term combustible.

Ques. What is fuel?

Ans. Any material which serves by combustion for the production of fire, as wood, coal, peat, oil, etc.

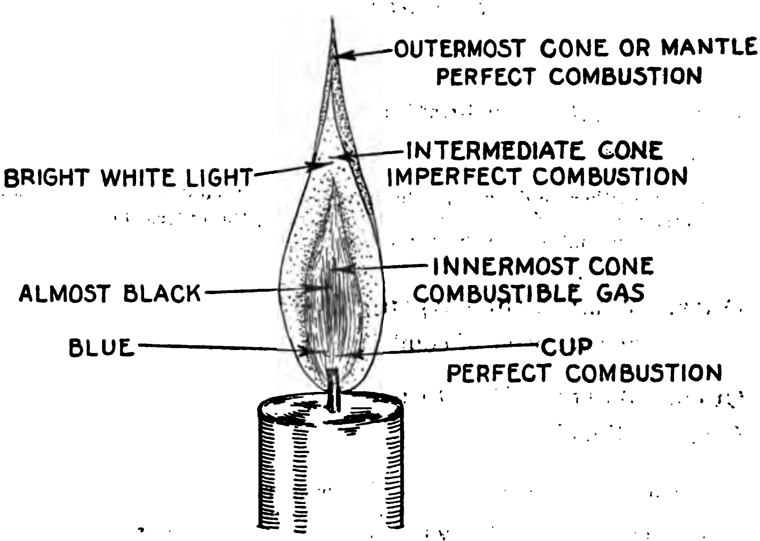


FIG. 3,340.—The candle flame. The form of the candle flame is common to all flames which consist of gas issuing from a small circular jet, like the wick of a candle. The gas issues from the jet in the form of a cylinder which, however, immediately becomes a diverging cone by diffusing into the surrounding air. When this cone is kindled, the margin of it, where interruption with the surrounding air is nearly complete, will be perfectly burned, but the gases in the interior of the diverging cone cannot burn until they have ascended sufficiently to meet with fresh air; since these unburned gases are continually diminishing in quantity, the successive circles of combustion must diminish in diameter resulting in the conical shape.

Combustible is that part of the fuel which burns. Fuel is made up of the material, and may also contain non-combustible matter.

Ques. What are the principal combustibles in coal and other fuels?

Ans. Carbon, hydrogen, and sulphur.

These occur in varying proportions, carbon being by far the most abundant, thus typical anthracite coals contain:

Carbon	90	to	95	per cent
Hydrogen	1	"	3	" "
Oxygen and nitrogen	1	"	2	" "
Moisture	1	"	2	" "
Ashes	3	"	5	" "

Carbon.—This is a combustible element, non-metallic in its nature, and present in most organic compounds

It forms the base of lamp black and charcoal and enters largely into mineral coals. In its crystallized state, it constitutes the diamond, the hardest of known substances, occurring in monometric crystals like the octahedron, etc. Another modification is graphite or black lead, and in this it is soft, and occurs in hexagonal prisms.

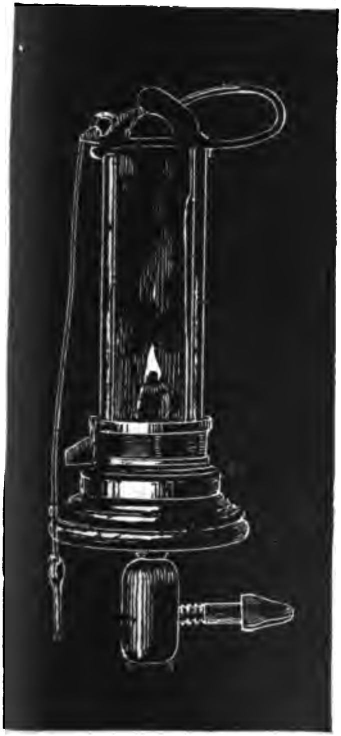
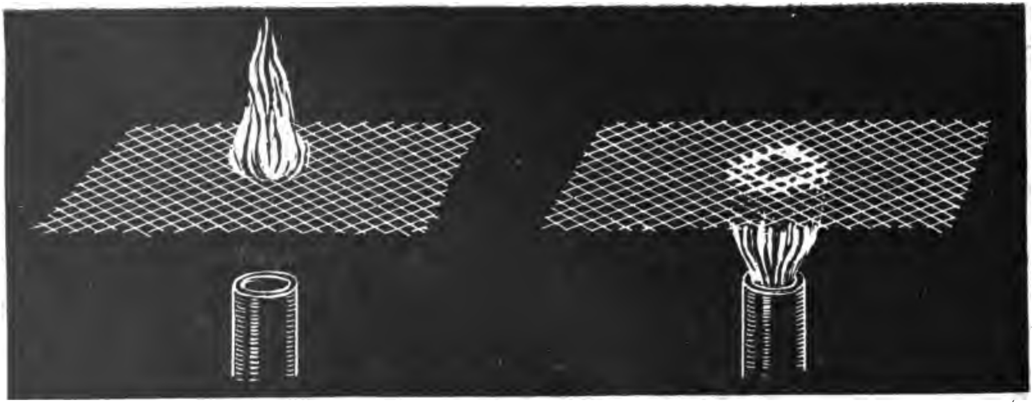


Fig. 3,341.—Davy's safety lamp. This lamp may be carried into a mine where there are explosive gases, and the gas may burn and splutter within the lamp but no explosion will take place in the mine. The reason for this is because a gas will not ignite until its temperature has been raised to a point called the ***kindling point***, and the wire gauze being a good conductor prevents the temperature rising to the kindling point, as illustrated in figs. 3,342 and 3,343. ***In construction,*** the safety lamp is an oil lamp, the flame of which is surrounded by a cage of iron wire gauze, having 700 or 800 meshes per square inch, and made double at the top, where the heat of the flame chiefly plays. The cage is protected by stout iron wires attached to a ring for suspending the lamp. A brass tube passes up through the oil reservoir and in this there slides, with considerable friction, a wire bent at the top, so that the wick may be trimmed without taking off the cage. The lower part of the cage is now made of glass, to afford more light.



FIGS. 3,342 and 3,343.—Principle of the Davy safety lamp: *A flame will not pass through wire gauze.* Let a piece of wire gauze be held above an open gas jet, and a match applied above the gauze. The flame will be found to burn above the gauze as in fig. 3,342, but it will not pass through to the lower side. If it be ignited below the gauze, the flame will not pass through to the upper side but will burn as shown in fig. 3,343. The reason for this is that *the gauze conducts the* ***heat away from the flame so rapidly that the*** *gas on the other side is not raised to the* ***kindling point,*** that is, to the temperature of ignition.

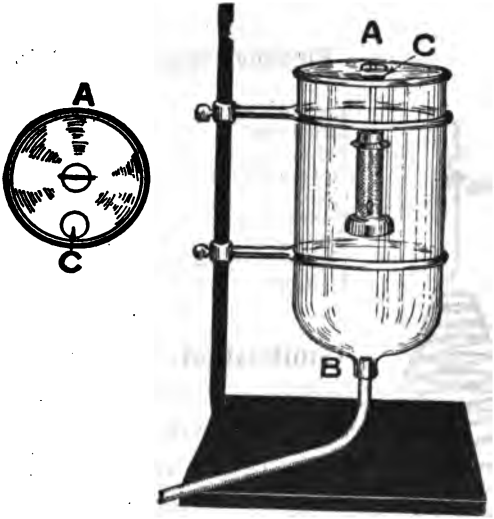
Carbon constitutes about one half of bituminous coal. It may be separated from wood in the form of charcoal by distilling off the more volatile elements.

Hydrogen.—Since hydrogen is the lightest of the elements, its organic weight is fixed as one, and the atomic weight of the other elements are multiples of the weight of hydrogen.

Hydrogen in a free state occurs in small quantities in some fuels but is usually in combination with carbon, in the form of hydrocarbons. The density of hydrogen is .0696 (air = 1) and its weight per cubic foot, at 32°F. and under atmospheric pressure, is .005621 pounds.

Sulphur.—Most coals and some oils contain sulphur. It is usually present in combined form, either as sulphide of iron or sulphate of lime; in the latter form it has no heat value.

Its presence in fuel is objectional because of its tendency to aid in the formation of clinkers, and the gases from its combustion, when in the presence of moisture, may cause corrosion.



FIGS. 3,344 and 3,345.—Experiment with Davy's lamp. If the lamp be suspended in a large jar, closed at the top with a perforated wooden cover A, and having an opening B, below through which coal gas is allowed to pass slowly into the jar, the flame will be seen to waver, to elongate very considerably, and finally to be extinguished, when the wire cage will be filled with a mixture of coal gas and air burning tranquilly within the gauze which prevents the flame passing to ignite the explosive atmosphere surrounding the lamp. As proof that the lamp is surrounded by an explosive mixture, a lighted taper inserted through the hole C, will cause an explosion.

Ignition or Kindling Point.—To cause a combustible to unite with oxygen and combustion take place, its temperature must be

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*NOTE.—When the Davy lamp is brought into an atmosphere containing fire damp, a *cap* of blue flame is observed to play above the tip of the illuminating flame. This incipient combustion is more marked when a hydrogen flame is substituted for an oil flame, and the height of the oil cap furnishes an indication of the quantity of fire damp present. Such a modified Davy lamp becomes a fire damp indicator.

raised to the ignition or kindling point, and a sufficient time must be allowed for the complete combustion to take place before the temperature of the gases is lowered below that point.

According to Stromeyer the approximate ignition temperatures are as given in the following table:

Kindling Temperature of Various Fuels.

	Degrees Fahr.
Lignite dust	300
Dried peat	435
Sulphur	470
Anthracite dust	570
Coal	600
Coke	red heat
Anthracite	red heat, 750
Carbon monoxide	red heat, 1211
Hydrogen	1,030 to 1,290

Combustion.—The two principal elements of coal, carbon and hydrogen, have an affinity for oxygen. When they unite chemically heat is produced. The oxygen having the stronger affinity for hydrogen unites with it first and sets the carbon free. A multiplicity of solid particles of carbon thus scattered in the midst of burning hydrogen are raised to a state of incandescence.

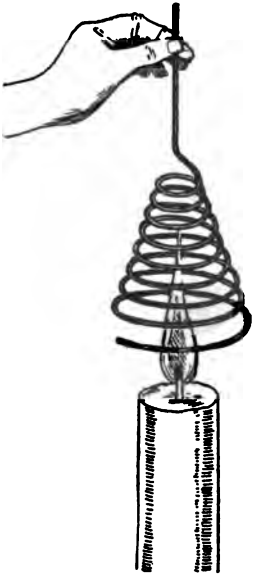
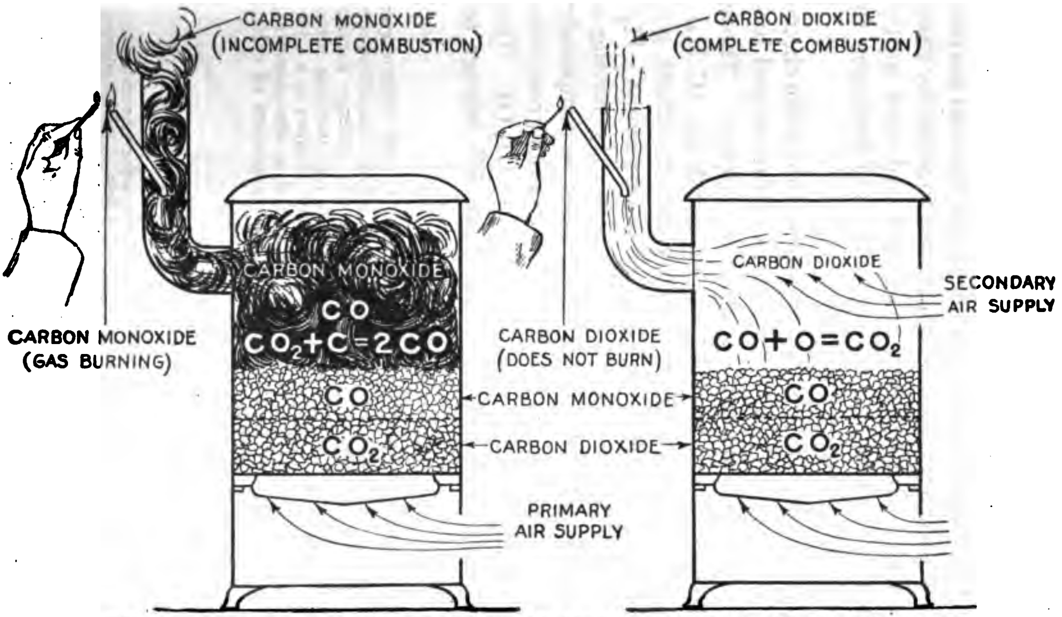


FIG. 3,346.—Experiment illustrating *the cooling of flame below the igniting temperature*. If a thin copper wire be coiled around into a helix and carefully placed over the wick of a burning candle, as shown, the heat of the flame will be transmitted along the wire so rapidly that the temperature will fall below the point at which combustible gases combine with oxygen, that is, below the *kindling point*, and here the flame will be extinguished. If the coil be heated to redness previously, the flame will not be extinguished. The cooling effect is also illustrated in the operation of an internal fire box boiler where the heat of the fuel lying next to the furnace walls is transmitted through the walls to the water so rapidly that the fire becomes "dead" along the walls.



Figs. 3,347 and 3,348.—Combustion in an ordinary stove illustrating incomplete (fig. 3,347) and complete (fig. 3,348) combustion. In fig. 3,347 air enters from below the grate only, and on passing through the lower layer of incandescent coal gives up its oxygen to the carbon of the coal forming carbon *dioxide*, thus:

carbon + oxygen = carbon dioxide

$$C + 2O = CO_2$$

As this carbon dioxide passes up through the upper layer of the coal where there is but little oxygen it gives up one-half of its oxygen to the carbon of the coal forming carbon *monoxide*, thus:

carbon dioxide + carbon = carbon monoxide

$$CO_2 + C = 2CO$$

The carbon, in due time, unites with the oxygen forming carbon dioxide or carbon monoxide.

The light and heat produced by the burning of the coal are due to the collision of atoms which have been urged together by their mutual attractions. During the process the hydrogen unites with the oxygen in the proportion of two atoms of hydrogen to one atom of oxygen to four of water (H_2O).

An important feature of the process of combustion is the chemical compounds formed by the combinations of carbon and hydrogen. These compounds are called *hydro-carbons*. Those most necessary to consider are methane or marsh gas ($C\,H_4$), having a heat value of 23,616 *B.t.u.*; ethylene or olefiant gas ($C_2\,H_4$) having a heat value of 21,344 *B.t.u.*; acetylene ($C_2\,H_2$) having a heat value of 18,196 *B.t.u.*; benzole ($C_6\,H_6$) having a heat value of about 18,000 *B.t.u.* If these gases be completely consumed so as to develop the number of heat units given, the products will be carbon dioxide ($C\,O_2$) and water ($H_2\,O$). The igniting temperature of these gases varies from 580 degrees to 667 degrees C.

Some of these hydro-carbons, such as marsh gas CH_4 and olefiant gas C_2H_4, burn without smoke, while others, like benzine C_6H_6 and naphthalene $C_{10}H_8$, which contain a very large proportion of carbon, undergo partial combustion, and a considerable quantity of carbon, not meeting with enough heated oxygen in the vicinity to burn it entirely, escapes in a very finely divided state as *smoke* or *soot*, which is deposited in the chimney, mixed with a little ammonium carbonate and small quantities of other products of the distillation of coal.

FIGS. 3,347 and 3,348.—*Text continued.*

If: 1, ***no air be admitted*** above the fuel level as in fig. 3,347, the carbon monoxide which is a combustible gas will pass up the chimney unburned ***resulting in a loss***, as will be indicated by inserting a tube in the stack and igniting the escaping carbon monoxide with a match; 2, when ***air is admitted*** above the fuel level as in fig. 3,348, the oxygen in the air will combine with the carbon monoxide already heated above the igniting temperature, causing complete combustion that is, burning the carbon monoxide to carbon dioxide, as indicated by attempting to ignite the gas escaping from the tube. It will not ignite, thus showing that the combustion is complete. Admitting more air than is necessary to secure complete combustion *results in a loss.*

When the gas has been expelled from the coal there remains a mass of *coke* or *cinder*, which burns with a steady glow until the whole of its carbon is consumed, and leaves an *ash*, consisting of the mineral substances present in the coal.

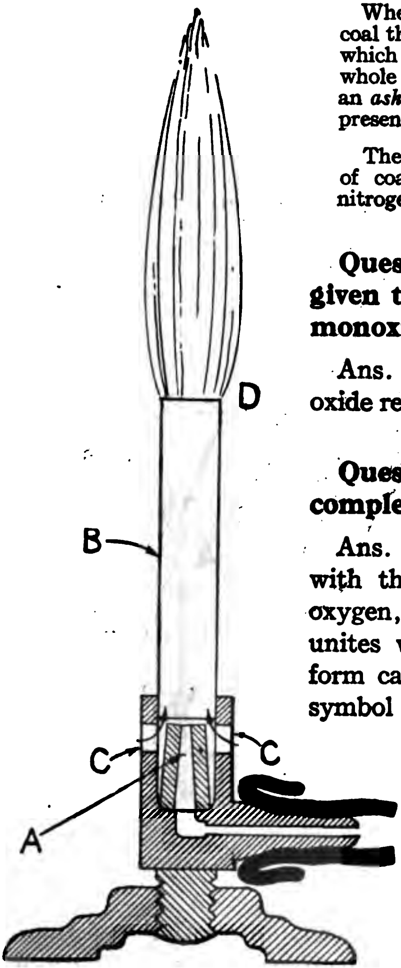
The final results of the perfect combustion of coal would be carbon dioxide, water, nitrogen, a little sulphur dioxide and ash.

Ques. What other names are given to carbon dioxide and carbon monoxide?

Ans. Carbonic acid and carbonic oxide respectively.

Ques. When is combustion complete?

Ans. When the combustible unites with the greatest possible amount of oxygen, as when one atom of carbon unites with two atoms of oxygen to form carbon dioxide, whose chemical symbol is CO_2.



CO_2—This gas is sometimes called carbonic anhydrid. It is heavy and colorless with a pungent odor. On account of

FIG. 3,349.—Bunsen Burner. ***It consists of*** **a small tube or burner A, which is placed inside a larger tube B. The latter has holes CC, a little below the top of the small tube. The current of gas escaping from the small tube draws the air in through the holes CC, and produces what is called an *induced current* of air in the large tube. This air enters through the holes CC, and is mixed with the gas in the tube B, and the mixture is burned at D. The flame from such a burner gives hardly any light, but the heat is intense, as is shown if a metal wire be held in it for a few seconds, it will glow with heat.**

its weight, it does not mix readily with other gases or the air, but collects at lowest levels as near the floor in rooms. It does not support combustion, nor is it a supporter of respiration.

Formerly it was thought that carbon dioxide was poisonous, but now the opinion is that it causes death by excluding oxygen. The fact that it is beneficial to the system if taken into the stomach proves that it is not poisonous.

Ques. When is combustion incomplete and why?

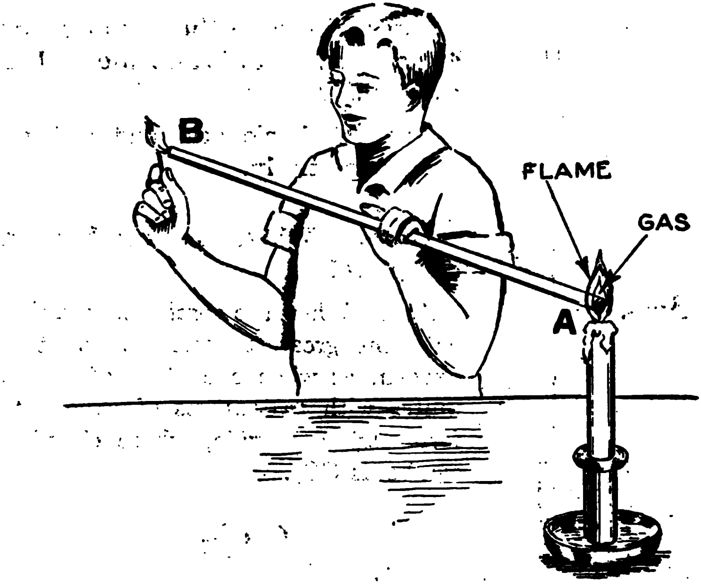


FIG. 3,350.—Experiment showing that *combustion occurs only at the surface of an ordinary flame*. Insert one end A, of a small open tube into the flame. The combustible gas will then escape at the other end B, and can be lighted with a match.*

Ans. When the combustible does not unite with the maximum amount of oxygen, as when one atom of carbon unites with one atom of oxygen to form carbon monoxide, whose chemical symbol is CO. The combustion is incomplete because the carbon monoxide (CO) may be further burned to carbon dioxide (CO_2).

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*NOTE.—It will be found that the flame from a Bunsen burner is considerably more intense than that of an ordinary candle or gas burner, because since the air is thoroughly mixed with the gas in a Bunsen burner, combustion takes place throughout instead of only at the surface.

This gas is colorless, without taste and with but little odor. It readily combines with oxygen to form CO_2, and its chief property is its poisonous nature. It is the deadly constituent of water gas.

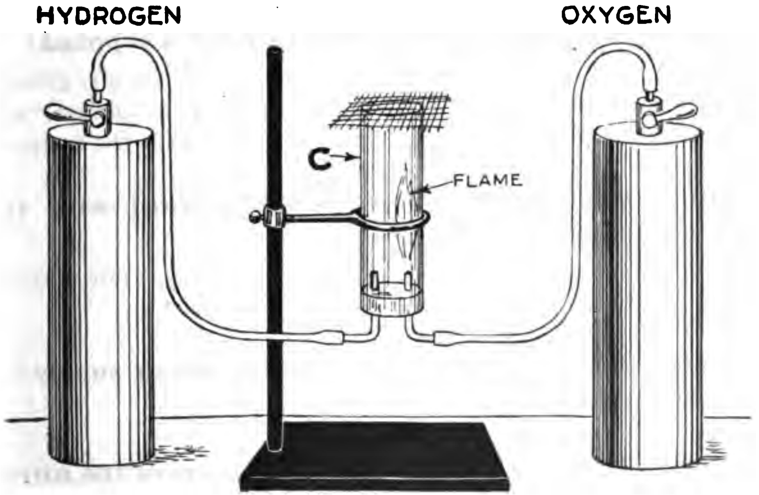

FIG. 3,351.—Experiments illustrating that the *combustible* may become the *supporter of combustion*, and the supporter of combustion become the combustible. Hydrogen is generally designated as a combustible and oxygen the supporter of combustion. Hydrogen and oxygen reservoirs are connected with two bent glass tubes passing through a cork into an ordinary lamp glass *c*, upon the upper opening of which wire netting is laid.* The hydrogen being lighted and the oxygen turned on to about the same extent, the lamp glass is placed over the cork, where the hydrogen burns steadily. If the oxygen be turned almost off, the flame will gradually leave the hydrogen tube and come over to the oxygen which will continue burning in the atmosphere of hydrogen. By again turning on the oxygen, the flame may be sent over to the hydrogen tube. With a little care the flame may be made to occupy an intermediate position between the two tubes. The experiment may also be performed with coal gas and oxygen.

Ques. What causes incomplete combustion?

Ans. Insufficient supply of air.

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*NOTE.—In order to prevent the ends of the glass tubes being fused by the burning gases, little platinum tubes, made by rolling up pieces of platinum foil, are placed in the orifices, and the glass is melted around them by the blow pipe flame.

If too little air be admitted to the fire *there will not be enough oxygen present to supply two atoms of oxygen to each atom of carbon liberated, hence carbon monoxide will be formed having a heating value of only 4,450 B.t.u., instead of carbon dioxide which has a heating value of 14,500 B.t.u.*

Thus when CO is formed instead of CO_2 because of lack of air supply, which contains the necessary oxygen, there will be a loss of approximately 69% of the fuel.

Ques. What results when too much air is supplied?

Ans. Since carbon cannot combine with oxygen in any greater ratio than two atoms of oxygen to one atom of carbon, any excess air supply simply dilutes the gases and cools the furnace.

Ques. Are steam boilers usually operated with too much air supply?

Ans. Yes, an excess supply as large as 150% is not uncommon, too much draught being as a rule employed.

Ques. What is the effect of heating the air supply?

Ans. It increases the rate of combustion.

Ques. What are the objectionable effects of the nitrogen contained in the air supply?

Ans. In passing through the furnace without change it dilutes the air, absorbs heat, reduces the temperature of the product for combustion, and is the chief source of heat losses in furnaces.

Ques. What is the useful effect of nitrogen?

Ans. It prevents too rapid combustion.

Without the large proportion of nitrogen in the atmosphere, the latter would be so rich in oxygen, that the resulting high rate of carbonation would burn out the grates.

Ques. How much air is required for combustion?

Ans. One pound of carbon requires 2⅔ pounds of oxygen for its complete combustion to carbon dioxide, or about 12 pounds of air. When the combustion is not perfect 1 pound of carbon burned to carbon monoxide requires 1⅓ pounds of oxygen, or about 6 pounds of air.

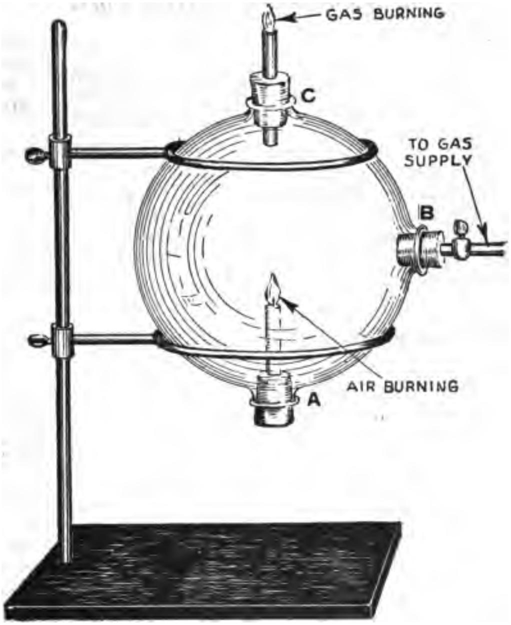

Fig. 3,352.—Experiment illustrating that the ***combustible*** may become the ***supporter of combustion***, and the supporter of combustion become the combustible. Take a flask having three openings A, B, and C, insert tubes at A, and C, as shown and connect B, with a supply of coal gas. Turn on the gas at B, and it may be lighted at C. Now if a lighted match be quickly thrust up the tube A, the air which enters it will take fire and burn inside the globe.

It has been impressed on the engineer's mind that, theoretically, coal requires 12 pounds of air for its combustion and, in practice, 50 per cent in excess of this, or 18 pounds. These values are frequently used by teachers, writers of engineering articles and designers of various apparatus for the boiler plant. While it is an easily remembered approximate in round numbers, the "12 pounds of air per pound of coal" does not hold true, as can be seen in the first column of the table, since the theoretical amount of air per pound of coal varies between 7 and a little over 11 pounds.

Air Required for Different Fuels

Fuel	Air theoretically required per pound of coal	Air theoretically required per 10,000 *B.t.u.*, generated
Illinois bituminous, poor quality	7.0	7.6
Illinois bituminous, good quality	9.4	7.55
Anthracite, average	10.2	7.65
Semibituminous, Pocahontas	11.2	7.5
Liquid fuel	14.24	7.04

Let the ultimate analysis be as follows:

	Per cent
Carbon	74.79
Hydrogen	4.98
Oxygen	6.42
Nitrogen	1.20
Sulphur	3.24
Water	1.55
Ash	7.82
	100.00

When complete combustion takes place, as already pointed out, the carbon in the fuel unites with a definite amount of oxygen to form CO_2. The hydrogen, either in a free or combined state, will unite with oxygen to form water vapor, H_2O. Not all of the hydrogen shown in a fuel analysis, however, is available for the production of heat, as a portion of it is already united with the oxygen shown by the analysis in the form of water, H_2O. Since the atomic weights and H and O are respectively 1 and 16, the weight of the combined hydrogen will be $\frac{1}{8}$ of the weight of the oxygen, and the hydrogen available for combustion will be $H - \frac{1}{8}\,O$. In complete combustion of the sulphur, sulphur dioxide SO_2 is formed, which in solution in water forms sulphuric acid.

Expressed numerically, the theoretical amount of air for the above analysis is as follows:

$$
\begin{array}{lr}
.7479\ \mathrm{C} \times 2\frac{2}{3} & = 1.9944\ \mathrm{O\ needed} \\
\left(.0498 - \frac{.0642}{8}\right) \mathrm{H} \times 8 & = \ .3262\ \mathrm{O\ needed} \\
.0324\ \mathrm{S} \times 1 & = \ .0324\ \mathrm{O\ needed} \\
\hline
\mathrm{Total} & 2.3530\ \mathrm{O\ needed}
\end{array}
$$

One pound of oxygen is contained in 4.32 pounds of air.

The total air needed per pound of coal, therefore, will be 2.353 × 4.32 = 10.165.

The weight of combustible per pound of fuel is .7479 + .0418* + .0324 + .012 = .83 pounds, and the air theoretically required per pound of combustible is 10.165 ÷ .83 = 12.2 pounds.

The above is equivalent to computing the theoretical amount of air required per pound of fuel by the formula:

$$\text{Weight per pound} = 11.52\ \mathrm{C} + 34.56\left(\mathrm{H} - \frac{\mathrm{O}}{8}\right) + 4.32\ \mathrm{S} \qquad (10)$$

where C, H, O and S, are proportional parts by weight of carbon, hydrogen, oxygen and sulphur by ultimate analysis.

Ques. Is it possible in practice to obtain perfect combustion with the theoretical amount of air?

Ans. No.

An excess is required, amounting to sometimes double the theoretical supply, depending upon the nature of the fuel to be burned and the method of burning it. The reason for this is that it is impossible to bring each particle of oxygen in the air into intimate contact with the particles in the fuel that are to be oxidized, due not only to the dilution of the oxygen in the air by nitrogen, but because of such factors as the irregular thickness of the fire, the varying resistance to the passage of the air through the fire in separate parts on account of ash, clinker, etc.

Ques. Is as large an excess of air required for oil as for coal?

Ans. No.

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*NOTE.—Available hydrogen.

Where the difficulties of drawing air uniformly through a fuel bed are eliminated, as in the case of burning oil fuel or gas, the air supply may be materially less than would be required for coal.

Experiment has shown that coal will usually require 50 per cent more than the theoretical net calculated amount of air, or about 18 pounds per pound of fuel either under natural or forced draught, though this amount may vary widely with the type of furnace, the nature of the coal, and the method of firing.

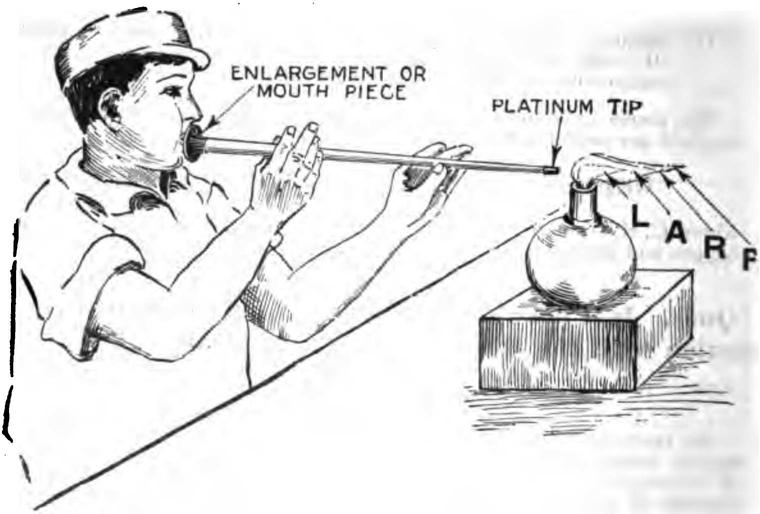

FIG. 3,353.—The ***blow pipe.*** The pipe is at right angles to the burner as shown. ***It consists of*** a metal tube provided with a platinum tip at one end and an enlargement at the other so shaped as to cover the lips of the operator who blows through the enlarged end. ***In operation,*** the stream of air should not be propelled from the lungs of the operator (where a great part of its oxygen would have been consumed), but from the mouth by the action of the muscles. The size of the flame, which is non-luminous, is much diminished, and the combustion being concentrated into a smaller space, the temperature must be *much* higher at any given point of the flame. ***Instructions:*** the blow pipe flame is similar to the ordinary flame, consisting of three distinct cones: ***1***, the innermost cone **L**, is filled with the cool mixture of air and combustible gas; ***2***, the second cone **A**, especially at its point **R**, is termed the *reducing flame*, because the supply of oxygen at that point is not sufficient to convert the carbon into carbon dioxide, but leaves it as carbon monoxide, which quickly reduces almost all metallic oxides placed in that part of the flame to the matallic state; ***3***, the outermost cone **F**, is called the *oxidising flame*, because at that point the supply of oxygen from the atmosphere is unlimited, and any substance which tends to combine with oxygen at a high temperature is oxidized when exposed to the action of that part of the flame. ***The hottest part*** of the flames where another fuel or oxygen is in excess, appears to be a very little in advance of the extremity of the reducing cone **A**.

If less than this amount of air be supplied, the carbon burns to monoxide instead of dioxide and its full heat value is not developed.

An excess of air is also a source of waste, as the products of combustion will be diluted and carry off an excessive amount of heat in the chimney gases, or the air will so lower the temperature of the furnace gases as to delay the combustion to an extent that will cause carbon monoxide to pass off unburned from the furnace.

A sufficient amount of carbon monoxide in the gases may cause the action known as secondary combustion, by igniting or mingling with air after leaving the furnace or in the flues or stack. Such secondary combustion which takes place either within the setting after leaving the furnace or in the flues or stack always leads to a loss of efficiency and, in some instances, leads to overheating of the flues and stack.

Calculated Theoretical Amount of Air Required per pound of Various Fuels

Fuel	Weight of constituents in one pound dry fuel			Air required per pound of fuel pounds
	Carbon per cent	Hydrogen per cent	Oxygen per cent	
Coke	94.	...	...	10.8
Anthracite coal	91.5	3.5	2.6	11.7
Bituminous coal	87.	5.	4.	11.6
Lignite	70.	5.	20.	8.9
Wood	50.	6.	43.5	6.
Oil	85.	13.	1.	14.3

Heating Values of Fuels.—To the engineer the heating value of any fuel is the amount of water it will evaporate; that is to say how many pounds of water will one pound of fuel evaporate. In calculations of this kind the result is brought down to a comparative *basis of evaporation from and at 212 degrees Fahrenheit,* and mean atmospheric pressure. Under this condition one pound of water is turned into steam by the addition of 970.4 heat units. The quantity of water which can be evaporated under these conditions by one pound of pure and dry carbon is 14.94 pounds. As a heat unit is equal to 778 foot pounds, and as a pound of carbon contains about 14,500 heat units, the heat it contains would be equal to 14,500 multiplied by 778 = 1,281,000 foot pounds.

In the case of hydrogen, one pound of the fuel would evaporate about 65 pounds of water.

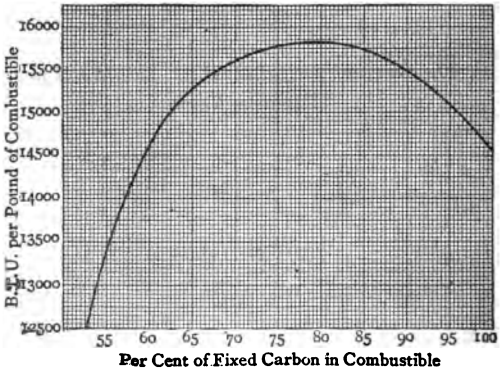

Fig. 3,354.—Curve of relation between heat value per pound of combustibles, and fixed carbon in combustible as deduced by Kent.

Determination of the Heating Value.—The heating value of a fuel may be determined either by burning a sample in a calorimeter or by calculation from a chemical analysis. When accuracy is desired, the first method should be used, as it is definitely known that coals having practically the same ultimate analyses show a difference in thermal value when burned in a calorimeter. This difference is due to the manner in which the elementary constituents of the fuel are combined and cannot be determined by chemical analysis.

When the heating value is determined by calculation from a chemical analysis, the calculation should be based on an ultimate analysis, which reduces the fuel to its elementary constituents of carbon, hydrogen, oxygen, nitrogen, sulphur, ash and moisture, to secure a reasonable degree of accuracy.

A proximate analysis, which determines only the percentage of moisture, fixed carbon, volatile matter and ash, without determining the ultimate composition of the volatile matter, cannot be used for computing the heat of combustion with the same degree of accuracy as an ultimate analysis, but estimates may be based on the ultimate analysis that are fairly correct.

An ultimate analysis requires the services of a competent chemist, and the methods to be employed in such a determination will be found in any standard book on engineering chemistry. An ultimate analysis, while resolving the fuel into its elementary constituents, does not reveal how these may have been combined in the fuel. The manner of their combination undoubtedly has a direct effect upon their calorific value, as fuels having almost identical ultimate analyses show a difference in heating value when tested in a calorimeter. Such a difference, however, is slight, and very close approximations may be computed from the ultimate analysis.

Ultimate analyses are given on both a moist and a dry fuel basis. Inasmuch as the latter is the basis generally accepted for the comparison of data, it would appear that it is the best basis on which to report such an analysis. When an analysis is given on a moist fuel basis it may be readily converted to a dry basis by dividing the percentages of the various constituents by one minus the percentage of moisture, reporting the moisture content separately.

	Moist fuel	Dry fuel
Carbon (C)	83.95	84.45
Hydrogen (H)	4.23	4.25
Oxygen (O)	3.02	3.04
Nitrogen (N)	1.27	1.28
Sulphur (S)	.91	.91
Ash	6.03	6.07
		100.00
Moisture	.59	.59
	100.00	

Calculations from an Ultimate Analysis.—The first formula for the calculation of heating values from the composition of fuel as determined from an ultimate analysis is due to

Dulong, and this formula, slightly modified, is the most commonly used today. Other formulæ have been proposed, some of which are more accurate for certain specific classes of fuel, but all have their basis in Dulong's formula, the accepted modified form of which is:

The heating value per pound of dry fuel is

$$B.t.u. = 14{,}600\ C + 62{,}000 \left(H - \frac{O}{8}\right) + 4{,}000\ S$$

where C, H, O and S are the proportionate parts by weight of carbon, hydrogen, oxygen and sulphur.

Assume a coal of the composition given. Substituting in this formula (18),

Heating value per pound of dry coal

$$= 14{,}600 \times .8445 + 62{,}000\ (.0425 - \frac{.0304}{8}) + 400 \times .0091 = 15{,}093\ B.t.u.$$

This coal, by a calorimetric test, showed 14,843 *B.t.u.*, and from a comparison the degree of accuracy of the formula will be noted.

The investigation of Lord and Haas in this country, Mahler in France, and Bunte in Germany, all show that Dulong's formula gives results nearly identical with those obtained from calorimetric tests and may be safely applied to all solid fuels except cannel coal, lignite, turf and wood, provided the ultimate analysis be correct. This practically limits its use to coal.

The limiting features are the presence of hydrogen and carbon united in the form of hydrocarbons. Such hydrocarbons are present in coals in small quantities, but they have positive and negative heats of combination, and in coals these appear to offset each other, certainly sufficiently to apply the formula to such fuels.

***Determination of Air Required for Combustion.**—Each combustible element in fuel will unite with a definite amount of

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*NOTE.—From Babcock & Wilcox's book entitled "Steam."

Oxygen and Air Required for Combustion at 32 Degrees and 29.92 Inches

By Weight

1	2	3	4	5	6	7	8	9	10
Oxidisable Substance or combustible	Chemical symbol	Atomic or combining weight	Chemical reaction	Product of combustion	Oxygen per pound of column 1 pounds	Nitrogen per pound of column 1 = 332* x C pounds	Air per pound of column 1 = 4.32† x O pounds	Gaseous product per pound of column 1 = 1+ column 8 pounds	Heat value per pound of column 1 *B.t.u.*
Carbon..........	C	12	$C+2O=CO_2$	Carbon dioxide...	2.667	8.85	11.52	12.52	14,600
Carbon..........	C	12	$C+O=CO$	Carbon monoxide.	1.333	4.43	5.76	6.76	4,450
Carbon monoxide.	CO	28	$CO+O=CO_2$	Carbon dioxide...	.571	1.9	2.47	3.47	10,150‡
Hydrogen........	H	1	$2H+O=H_2O$	Water...........	8	26.56	34.56	35.56	62,000
Methane.........	CH_4	16	$CH_4+4O=$ CO_2+2H_2O	Carbon dioxide and water......	4	13.28	17.28	18.28	23,550
Sulphur..........	S	32	$S+2O=SO_2$	Sulphur dioxide...	1	3.32	4.32	5.32	4,050

oxygen. With the ultimate analysis of the fuel known, in connection with the table here given, the theoretical amount of air required for combustion may be readily calculated.

"Available" Heating Value.—The heating value of hydrogen has been given as in round numbers, being 62,000 *B.t.u.* The exact figures are given higher or lower by different authorities, but the higher figures seem to have the sanction of the U. S. Government in making coal tests, or 62,032, the amount given by Favre and Silberman.

That it will not pay to decompose the hydrogen in water for the purpose of burning it as fuel can be clearly

Oxygen and Air Required for Combustion at 32 Degrees and 29.92 Inches

By Volume

1	2	11	12	13	14	15	16	17	18
Oxidizable substance or combustible	Chemical symbol	Volumes of column 1 entering combination volume	Volumes of oxygen combining with column 11 volume	Volumes of product formed volume	Volume per pound of column 1 in gaseous form cubic feet	Volume of oxygen per pound of column 1 cubic feet	Volume of products of combustion per pound of column 1 cubic feet	Volume of nitrogen per pound of column 1 = 3.782§ x column 15 cubic feet	Volume of gas per pound of column 1 = column 16+column 17 cubic feet
Carbon..........	C	1C	2	$2CO_2$	14.95	29.89	29.89	112.98	142.87
Carbon..........	C	1C	1	2CO	14.95	14.95	29.89	56.49	86.38
Carbon monoxide.	CO	2CO	1	$2CO_2$	12.80	6.40	12.80	24.20	37.00
Hydrogen........	H	2H	1	$2H_2O$	179.32	89.66	179.32	339.09	518.41
Methane.........	CH_4	1C4H	4	$1CO\ 2H_2O$	22.41	44.83	67.34	169.55	236.89
Sulphur..........	S	1S	2	$1SO_4$	5.60	11.21	11.21	42.39	53.60

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* Ratio by weight of O to N in air.

† 4.32 pounds of air contains one pound of O.

‡ Per pound of C in the CO.

§ Ratio by volume of O to N in air.

perceived by a study of the process of decomposition that takes place.

If nine pounds of water which would result from the burning of one pound of hydrogen and the giving off of 62,000 heat units, the water being cooled to the temperature of the air, be passed into a hot furnace, it will be decomposed into eight pounds of oxygen and one pound of hydrogen. The energy consumed in doing this work will equal 62,000 heat units, which will be absorbed from the heat of the furnace. The so called *available heating value* of it is obtained as follows:

Example—If one pound of hydrogen to be burned in just enough air to supply 8 pounds of oxygen, the hydrogen and air be supplied at 62°, and the products of combustion escape at 212°F., what is the net available heating value?

	B.t.u.	*B.t.u.*
Total heating value of 1 pound of hydrogen........		62,000
Heat lost, latent of 9 pounds of water at 212°F. = 970.4×9	8,733.6	
Nine pounds of water heated from 62°F. to 212°F..	1,349.3	
Nitrogen with 8 pounds oxygen heated from 62°F. to 212°F. = 8×3.32×150×.2438 (specific heat)	971	11,053.9
Net available heating value........................	11,053.9	50,946.1

Example—If the air supply be double that required to effect the combustion of the hydrogen, the other conditions being the same as in the first example, what is the net heating value?

	B.t.u.
Net available heating value (from example 1)..........	50,946.1
Excess air 8×4.32 pounds	
	B.t.u.
Heat loss due to excess air 4.32*×150×.2375† = 1,231	1,231
Net heating value (including loss by excess air)........	59,715.1

*NOTE.—4.32 is the proportion of air to oxygen by weight;

†NOTE.—.2375 is the specific heat of air.

Example—If with double air supply the products of combustion escape at 562°, what is the total loss and net available heating value?

	B.t.u.	*B.t.u.*
Total heating value of 1 pound of hydrogen........		62,000
Nine pounds of water heated from 62°F. to 212°F..	1,349.3	
Latent heat of 9 pounds of water at 212°F. = 970.4×9	8,733.6	
Degrees of superheat = 562—212=350.		
Superheated steam, 9×350×.48*	1,512	
Nitrogen, 26.56×350×.2438†....................	3,238	
Excess air 34.56×350×.2375....................	4,104	
Total loss..................................	18,936.9	18,936.9
Net available heating value......................		43,063.1

*NOTE.—Specific heat of superheated steam.

†NOTE.—Specific heat of nitrogen.

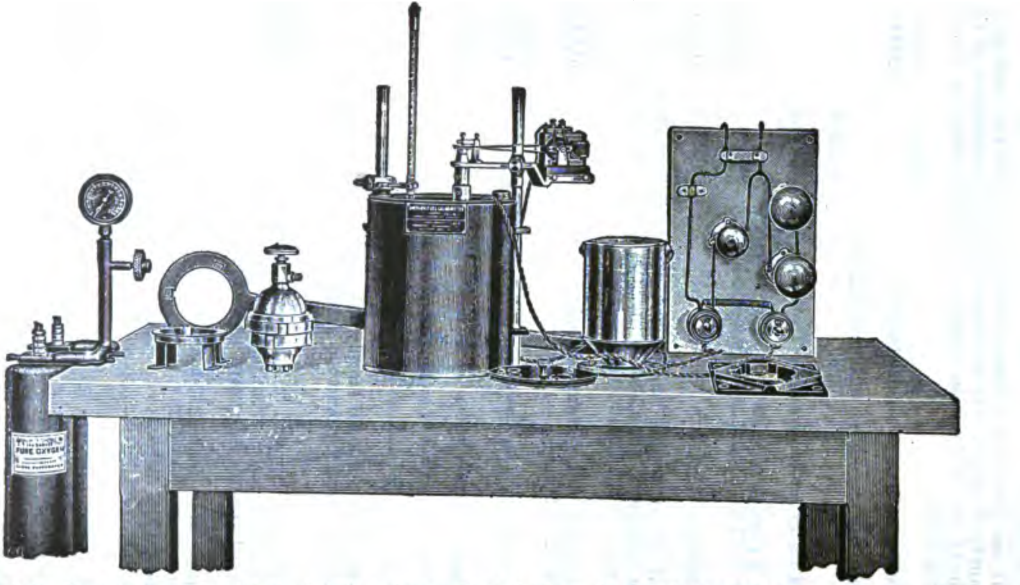


FIG. 3,355.—Emerson oxygen bomb fuel calorimeter. The outfit for the determination of the heat values of fuels and combustibles consists primarily of a strong steel receptacle (called a bomb) into which the sample of combustible is placed, and within which it is completely burned. The sample is prepared in a finely divided condition, and to insure complete combustion is placed in the bomb in the presence of pure oxygen under high pressure. At the desired time, the fuel is ignited by means of a fuse wire dipping into the sample. This wire is brought to incandescence by means of the passage of an electric current. During combustion, the bomb is entirely immersed in a known amount of water. The rise in temperature of the water is accurately measured with a standard thermometer. The product of this rise in temperature and the known weight of water (plus the water equivalent of the bomb and other immersed metal parts) gives directly the heat units given off by the burning of the sample, the weight of which has been determined previously. From this data, the *B.t.u.* per pound can be determined, this being the commercial value desired for industrial purposes.

High and Low Heat Value of Fuels.—In any fuel containing hydrogen the calorific value as found by the calorimeter is higher than that obtainable under most working conditions in boiler practice by an amount equal to the latent heat of the volatilization of water. This heat would reappear when the vapor was condensed, though in ordinary practice the vapor passes away uncondensed. This fact gives rise to a division in heat values into the so-called "higher" and "lower" calorific values.

The higher value, *i. e.*, the one determined by the calorimeter, is the only scientific unit, is the value which should be used in boiler testing work, and is the one recommended by the American Society of Mechanical Engineers.

There is no absolute measure of the lower heat of combustion, and in view of the wide difference in opinion among physicists as to the deductions to be made from the higher or absolute unit in this determination, the lower value must be considered an artificial unit. The lower value entails the use of an ultimate analysis and involves assumptions that would make the employment of such a unit impracticable for commercial work. The use of the low value may also lead to error and is in no way to be recommended for boiler practice.

An example of its illogical use may be shown by the consideration of a boiler operated in connection with a special economizer where the vapor produced by hydrogen is partially condensed by the economizer. If the low value were used in computing the boiler efficiency, it is obvious that the total efficiency of the combined boiler and economizer must be in error through crediting the combination with the heat imparted in condensing the vapor and not charging such heat to the heat value of the coal.

Heating Value of Gaseous Fuels.—The method of computing calorific values from an ultimate analysis is particularly adapted to solid fuels, with the exceptions already noted. The heating value of gaseous fuels may be calculated by Dulong's formula provided another term is added to provide for any carbon monoxide present.

Such a method, however, involves the separating of the constituent gases into their elementary gases, which is oftentimes difficult and liable to simple arithmetical error.

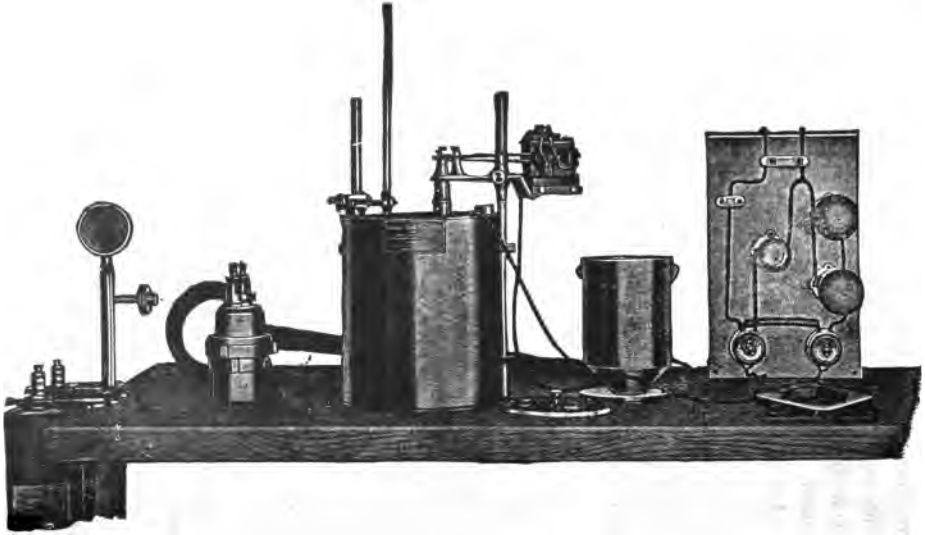


FIG. 3,356.—Emerson double valve type calorimeter. This outfit is suitable for the determination of the heat of combustions of fuel, etc., and for the determination of the sulphur content of combustibles. It is used in the same manner for this work as the Standard outfit with the single valve bomb. In addition to these above uses, the double valve bomb offers opportunity for analyzing the products of combustion which are formed in the bomb during ignition of the material under test. A particular application of the instrument used in this manner is the determination of the percentage of carbon in steel, by burning the same in the bomb in the presence of an excess of oxygen under pressure, in the same manner as a fuel, and subsequently analyzing the gases as they are exhausted from the bomb.

As the combustible portion of gaseous fuels is ordinarily composed of hydrogen, carbon monoxide and certain hydrocarbons, a determination of the calorific value is much more readily obtained by a separation into their constituent gases and a computation of the calorific value from a table of such values of the constituents.

The accompanying table gives the calorific value of the more common combustible gases, together with the theoretical amount of air required for their combustion.

Weight and Heating Value of Various Gasses at 32° F. and Atmospheric Pressure with Theoretical Amount of Air Required for Combustion

Gas	Symbol	Cubic feet of gas per pound	*B.t.u.* per pound	*B.t.u.* per cubic foot	Cubic feet of air required per pound of gas	Cubic feet of air required per cubic foot of gas
Hydrogen..........	H	177.90	62000	349	428.25	2.41
Carbon monoxide...	CO	12.81	4450	347	30.60	2.3
Methane...........	CH^4	22.37	23550	1053	214.00	9.57
Acetylene.........	C_2H_2	13.79	21465	1556	164.87	11.93
Olefiant gas........	C^2H^4	12.80	21440	1675	183.60	14.33
Ethane............	C^3H^6	11.94	22230	1862	199.88	16.74

Example—Assume a blast furnace gas, the analysis of which in percentages by weight is, oxygen = 2.7, carbon monoxide = 19.5, carbon dioxide = 18.7, nitrogen = 59.1. Here the only combustible gas is the carbon monoxide, and the heat value will be,

$$.195 \times 4{,}350 = 848.25 \textit{ B.t.u.} \text{ per pound.}$$

The *net* volume of air required to burn one pound of this gas will be,

$$.195 \times 30.6 = 5.967 \text{ cubic feet.}$$

Example—Assume a natural gas, the analysis of which in percentages by volume is oxygen = .40, carbon monoxide = .95, carbon dioxide = .34, olefiant gas (C^2H^4) = .66, ethane (C^2H^6) = 3.55, marsh gas (CH^4) = 72.15 and hydrogen = 21.95. All but the oxygen and the carbon dioxide are combustibles, and the heat per cubic foot will be,

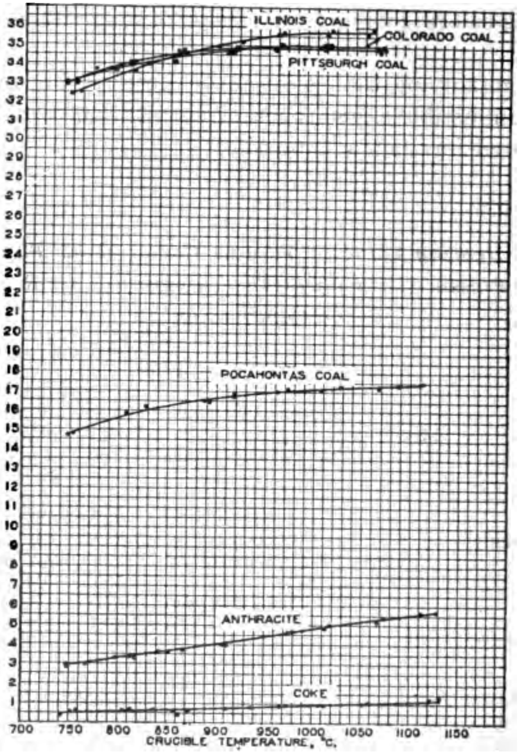


Fig. 3,357.—Percentage curves of volatile matter from different coals at various temperatures.

From CO = .0095 × 339 = 3.22
C^2H^4 = .0066 × 1,675 = 11.05
C^2H^6 = .0355 × 1,859 = 65.99
CH^4 = .7215 × 1,050 = 757.58
H = .2195 × 346 = 75.95

B.t.u. per cubic foot 913.79

The *net* air required for combustion of one cubic foot of the gas will be,

$CO = .0095 \times 2.39 = .02$
$C^2H^4 = .0066 \times 14.33 = .09$
$C^2H^6 = .0355 \times 16.74 = .59$
$C\,H^4 = .7215 \times 9.57 = 6.90$
$H = .2195 \times 2.41 = .53$

Total net air per cubic foot 8.13

Proximate Analysis.—The proximate analysis of a fuel gives its proportions by weight of fixed carbon, volatile combustible matter, moisture and ash. The following method of making such an analysis which has been fround to give eminently satisfactory results:

FIGS. 3,358 to 3,360.—Various crucibles. Fig. 3,358 royal Berlin glazed under and outside; fig. 3,359 Gooch, glazed with perforated bottom; fig. 3,360 normal school. This is a spun iron crucible for individual use of the laboratory student, or for general experimenting. It may be used equally well as an open crucible, a closed crucible, or a retort; and being of thin metal, is easily brought to a red heat in the flame of an ordinary burner. All parts interchangeable. Capacity, about 1½ ounce.

From the coal sample obtained on the boiler trial, an average sample of approximately 40 grams is broken up and weighed. A good means of reducing such a sample is passing it through an ordinary coffee mill. This sample should be placed in a double-walled air bath, which should be kept at an approximately constant temperature of 105 degrees centigrade, the sample being weighed at intervals until a minimum is reached. The percentage of moisture can be calculated from the loss in such a drying.

For the determination of the remainder of the analysis, and the heating value of the fuel, a portion of this dried sample should be thoroughly pulverized, and if it is to be kept, should be placed in an air-tight receptacle.

One gram of the pulverized sample should be weighed into a porcelain crucible equipped with a well fitting lid. This crucible should be supported on a platinum triangle and heated for seven minutes over the full flame of a Bunsen burner. At the end of such time the sample should be placed in a desiccator containing calcium chloride, and when cooled should be weighed. From the loss the percentage of volatile combustible matter may be readily calculated.

The same sample from which the volatile matter has been driven should be used in the determination of the percentage of ash. This percentage is obtained by burning the fixed carbon over a Bunsen burner or in a muffle furnace. The burning should be kept up until a constant weight is secured, and it may be assisted by stirring with a platinum rod.

The weight of the residue determines the percentage of ash, and the percentage of fixed carbon is easily calculated from the loss during the determination of ash after the volatile matter has been driven off.

Proximate analyses may be made and reported on a moist or dry basis. The dry basis is that ordinarily accepted. The method of converting from a moist to a dry basis is the same as described in the case of an ultimate analysis. A proximate analysis is easily made, gives information as to the general characteristics of a fuel and of its *relative* heating value.

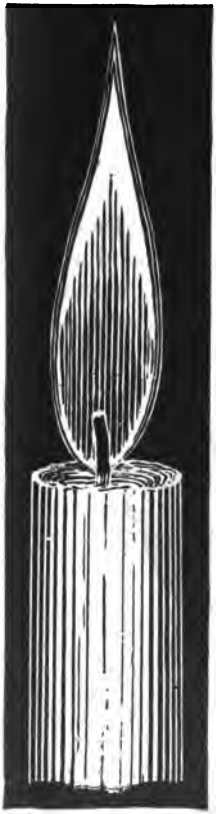


FIG. 3,361.—***The candle flame.*** It is seen to consist of three concentric cones. 1, the innermost around the wick, appearing almost black; 2, the next emitting a bright white light, and 3, the outermost being so pale as to be scarcely visible in broad daylight; there is also apparent a bright blue cup surrounding the base of the flame. 1, The dark innermost cone consists of the gaseous combustible to which the air does not penetrate, and which, therefore, is not in a state of combustion; 2, In the second or luminous cone combustion is proceeding, but it is by no means perfect, being attended by the separation of a quantity of carbon, which causes luminosity upon the part of the flame. The presence of free carbon is shown by depressing a piece of porcelain upon this cone when a black film of soot is deposited. The liberation of the carbon is due to the decomposition of the hydrocarbons by the heat, which separates the carbon from the hydrogen, and this latter, undergoing combustion evolves sufficient heat to raise the separated carbon to a white heat, the supply of air which penetrates into this portion of the flame being insufficient to affect the combustion of the whole of the carbon; 3, the pale outermost cone or *mantle* of the flame in which the separated carbon is finally consumed may be termed the cone of perfect combustion, and is much thinner than the luminous cone, the supply of air to the external shell of flame being unlimited and the combustion therefore speedily effected; 4, the bright blue cup surrounding the base of the flame is formed by the perfect combustion (without any separation of carbon) of a small portion of the hydrocarbons owing to the complete admixture of air at this point.

Flame.—Visible flame consists of combustible gas heated to an intense heat. If it come in contact with a supply of air in a chamber where the temperature is sufficiently high, it will burn, but if cooled before coming in contact with the air supply it will escape in an unburned state as gas or smoke. The product of perfect combustion is invisible. The product of the perfect combustion of carbon is invisible carbonic acid. The product of the perfect combustion of hydrogen is invisible water vapor.

As carbon is the principal constituent of coal the state of the combustion in the furnace is determined very closely by determining the amount of carbonic acid in the flue gases.

It is considered that when fresh coal is fired into a hot furnace that the first process which takes place is the evaporation of the moisture in the coal into steam. This results in the decomposition of more or less of the steam in contact with the carbon into hydrogen and carbonic oxide. Also some of the carbonic acid formed by union of oxygen with coal may be decomposed into carbonic oxide. These two processes both have a tendency to cool the furnace. The volatile matter is then distilled off and burned if the temperature of the furnace be high enough, and the air supply be sufficient.

If then the temperature and air supply be maintained, the coal or coke remaining is consumed except such mineral or earthy matter in it that is not combustible.

Smoke.—By definition smoke is a term applied to ***all*** *the products of combustion escaping from the furnace whether visible or invisible*. It is popularly and erroneously restricted to the visible product of combustion.

Ques. What are the black particles in smoke?

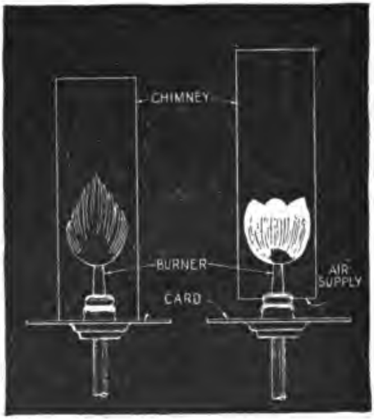
Ans. Solid carbon.

Ques. What does colored smoke indicate?

Ans. *Imperfect* combustion.

Most of the coals used as fuel in boiler furnaces contain substances that distill at low temperatures and are released when the coal is heated. These substances are commonly known as ***volatile matter.***

The amount and nature of these distillates vary widely, and upon their composition depends the amount and nature of the smoke produced.



FIGS. 3,362 and 3,363.—***Cause of smoke.*** When the supply of oxygen is insufficient to consume the particles of solid carbon they are set free and then assume the form of soot, the collection of these minute particles being called smoke. This can be illustrated by cutting a hole in a card, fig. 3,362, so as to fit over an ordinary gas burner. Now, light the gas and place a glass chimney over the burner, letting it rest on the card. The flame will at once begin to smoke, because very little air can then come in contact with the flame, and, therefore, when the fine particles of carbon are set free by the combustion of the hydrogen, instead of being burned, as they would be if the air with its supply of oxygen were not excluded from the flame by the chimney, they escape unconsumed in the form of black powder or soot. If the chimney be raised from the card, as in fig. 3,363, so as to permit air to enter space between them at the bottom of the chimney, as indicated by the arrows, and supply the flame with oxygen, the smoke will cease, as the particles of carbon are then consumed. The same principle is illustrated in an ordinary kerosene lamp. It is well known that without a chimney the flames of nearly all such lamps smoke intolerably, whereas with a glass chimney and the peculiarly formed deflector which surrounds the wick, the light burns without smoke unless the wick is turned up high. The effect of the chimney is to produce a draught which is thrown against the flame by the deflector, and thus a sufficient supply of oxygen is furnishedto consume all the particles of carbon, whereas, without tne draught produced by the chimney, the supply of oxygen is insufficient to ignite all the carbon, which then escapes in the form of smoke or soot. It must not, however, be hastily assumed that if the flame do not give out a bright light, therefore the combustion is not complete. As has already been stated, the light of the gas flame is due to the presence of burning particles of solid carbon, which is set free by the combustion of the hydrogen with which it is combined. After it is separated from the hydrogen it immediately assumes a solid form.

The volatile matter (this term does not include the moisture), consists of hydro-carbons which differ primarily in the temperatures at which they boil (distill), and in their ignition temperatures.

Furthermore, the lighter volatiles remain in a gaseous state when they are cooled. The heavier ones such as tar vapors, have a tendency to dissociate at certain temperatures, liberating the carbon particles. If sufficiently high temperatures prevail in the combustion chamber, and these carbon particles come into contact with free oxygen, they burn completely.

The incandescence of the highly heated carbon particles before their complete combustion produces the luminosity of the flame. If, however, oxygen be lacking in the combustion chamber, or if the oxygen do not come into contact with the carbon particles before the temperature drops below the ignition point, incomplete combustion takes place and the unburned carbons pass off as smoke.

Ques. Upon what does the smoke producing tendency of coals depend?

Ans. Since the various hydrocarbons differ in their readiness to dissociate, the smoke production of coal depends upon the *nature* rather than upon the *volume* of the volatile content.

Some coals, despite their relatively high percentage of volatile matter, do not tend to produce smoke as readily as others with less volatile content, such as lignites.

Ques. Is black smoke an indication of greatly reduced economy?

Ans. *No.*

The erroneous opinion prevails that black smoke contains a large amount of combustible matter and that it is a sign of considerable waste. The most dense smoke does not commonly contain more than ½ of 1 per cent of the combustible fired.

The extreme fineness and the distribution of the carbon particles bestow upon them a high coloring power. The carbon particles producing visible smoke are not derived from a lifting of fixed or solid carbon from the grates, but they are formed from gases during the combustion process.

Ques. How do the losses due to black smoke compare

with those due to incomplete combustion or excessive air, which generally accompany combustion without visible smoke?

Ans. They are negligible.

Ques. What is the effect when the air supply does not thoroughly mix with the gases from the fuel?

Ans. It causes slower combustion, resulting in a longer flame.

For instance, if the glass chimney be removed from the circular burner of a kerosene lamp a long, smoky flame is produced, but when the chimney is replaced the flame becomes short and clear. The reason for this is that the chimney produces a draught. That is, it creates a higher air velocity, and effects a good mixture of air and combustible gas.

The flame post over the bridge wall in a boiler furnace may be designed to achieve a similar effect.

Ques. How can the hyrdo-carbon gases be completely and smokelessly burned?

Ans. *By admitting and thoroughly mixing sufficient air before the gases are cooled below a certain temperature.*

Applying these principles to the combustion of volatiles in the boiler furnace, the following requirements must be met to effect complete and smokeless combustion.

1. Introduction of the proper amount of air to secure complete combustion.
2. Effective and early admixture of air and volatiles.
3. Sufficiently high temperatures in the combustion zone.

The complete fulfillment of these three cardinal conditions of smokeless combustion is rather difficult to obtain in the boiler furnace, especially the second requirement. Undue consideration is generally given to the maintenance of high temperatures in the combustion space. In the majority of cases insufficient air and particularly incomplete mixture are the causes of smoke products. This is especially true where bituminous coals are burned.

If care be taken to effect an early and complete mixture of sufficient air with the combustible gases, satisfactory combustion can be obtained in furnaces that are completely surrounded by heating surfaces.

Ques. As long as there are combustible gases in the furnace is a reasonable amount of excess air objectionable?

Ans. No.

The cooling of the flame through moderate air admission above the flame need not be feared. In fact, air must be provided above the grates to complete combustion, because generally the amount of air admitted through the grates is consumed in the fuel bed.

Ques. What is the effect of the heat storing and refractory properties of arches and piers in the combustion chamber?

Ans. They decrease the efficiency of the furnace and have a questionable influence upon the completeness of combustion.

The effect of such contrivances must be judged only by their ability to effect or prevent the thorough mixture of air and combustible gases. To achieve this, their location must be at the point of origin of flame development; that is, at or near the bridge wall.

Taking into consideration the fact that the absorption of heat by a surface through direct radiation is decidedly greater than the convection of heating surfaces in contact with the non-illuminant fuel gases, the exposure of the greatest possible amount of heating surface to the luminous flame is of prime importance to the economy of the boiler plant. Bearing this in mind, efforts must be directed to achieve the desired results with as little refractory brickwork as possible, as otherwise the success in smoke abatement will be gained at the cost of efficiency. This is of greater importance in the hand fired furnace than in the stoker furnace with continuous feed.

Ques. How should the combustion chamber be proportioned for burning bituminous coals?

Ans. It should be extra large.

Provision must be made to control the air supply above the fuel so as to supply additional oxygen to complete the combustion.

In admitting air above the fuel, unless it can be supplied at the right time and place, and in the right quantity, it may prove a worse evil than the smoke itself by lowering the temperature of the gases in the furnace to a point below which ignition will not take place.

Ques. How is smoke classified with respect to intensity?

Ans. By dividing it into several shades, or comparing it with a smoke chart.

Classification of Smoke.—According to numerous authorities, the best scale to adopt seems to be one having five shades:

1. White transparent vapor.

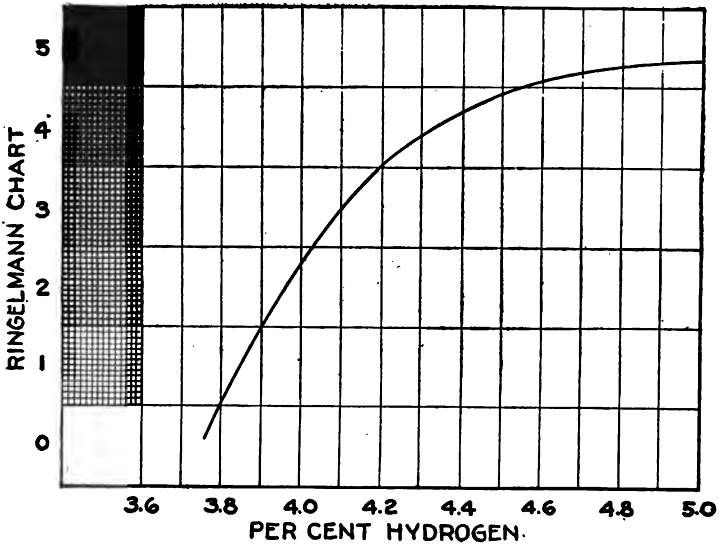


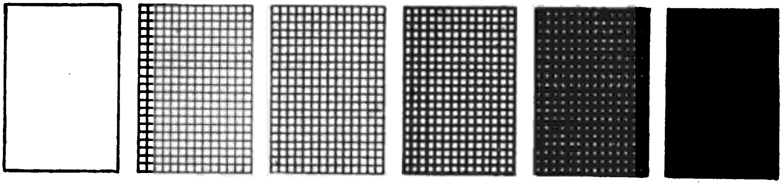
FIG. 3,364.—Ringelmann chart showing how the density of smoke varies with the percentage of hydrogen in the coal.

2. Light brown smoke.
3. Brownish gray smoke.
4. Dense smoke.
5. Thick black smoke.

The personal equation enters largely into the determination of the shade of smoke as must be evident.

Furnace Temperature.—The theoretical temperature of a furnace can be calculated by dividing the heat units produced by the combustion of the fuel by the weight of the gases multiplied by their respective specific heats.

If carbon were burned in the theoretical amount of pure oxygen necessary for complete combustion and all the heat developed in raising the temperature of the resulting gases utilized, a temperature of 18,000° Fahr. would be obtained.



FIGS. 3,365 to 3,370.—Ringelmann scale for grading smoke density. ***It consists of*** four large sheets ruled with vertical and horizontal lines forming squares as shown. No 1 is ruled with line 1 *mm* thick and spaced 9 *mm* wide; No. 2, 2.3 *mm* lines, 7.7 *mm* spaces; No. 3, 3.7 *mm* lines, 6.3 *mm* spaces; No. 4, 5.5 *mm* lines, 4.5 *mm* spaces. The cards are placed 50 feet from the observer in line with the chimney, together with a white and a solid black card. The observer glances quickly from the chimney to the cards and judges which one corresponds with the color and density of the smoke. Ringlemann readings are usually taken at ½ to 1 minute intervals during an hour or more. The readings are plotted in a log which gives a good general idea of the manner and regularity of smoke emission but is very unsatisfactory for ordinary stacks.

NOTE.—According to the *Am. Soc. of M. E.*, no wholly satisfactory methods for either quantitating or qualitating smoke determinations have yet come into use, nor have any reliable methods been established for definitely fixing even the relative density of the smoke issuing from chimneys at different times. One method commonly employed, which answers the purpose fairly well, is that of making frequent visual observations of the chimney at intervals of one minute or less for a period of one hour and recording the observed charactertistics according to the degree of blackness and density, and giving to the various degrees of smoke an arbitrary percentage value rated in some such manner as follows: ***dense black,*** 100%; ***medium black,*** 80%; dense gray, 60%; ***medium gray,*** 40%; ***light grey,*** 20%; very light, 5%; trace, 1%; clear chimney, 0. The shade and density of smoke depend somewhat on the character of the sky or other background, and on the air and weather conditions obtaining when the observation is made, and there should be given due consideration in making comparisons.

NOTE.—One of the latest methods for indicating and recording the density of smoke is one depending on the variations in the electrical conductivity of the metal selenium due to variations in the intensity of light shining upon it. Openings are provided on either side of the flue directly opposite each other. The intensity of the light rays falling on the selenium varies with the density of the smoke. A milli-ampere meter in circuit with the selenium cell registers the variations.

In burning coal, however, this amount of heat is never attained for various reasons. There are always losses by radiation and in other ways and the combustion process is never perfect except in calorimeter tests.

Instead of oxygen, air is used to support combustion and almost invariably an excess of air over that theoretically required for complete combustion, giving a much larger weight of gases to be heated.

Some of the heat available, in the coal is lost by incomplete combustion, by radiation to the exposed surfaces to the fuel bed, by dissociation of the resulting gases, by evaporating and superheating moisture in the coal and in the air supplied and by heating the ash.

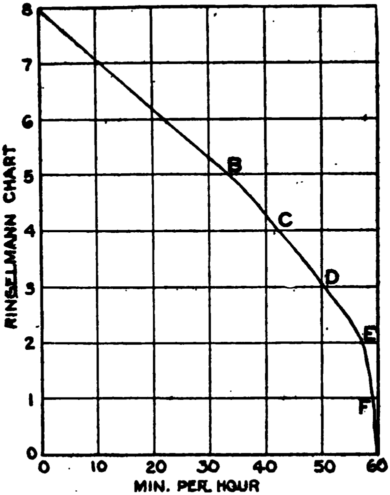


FIG. 3,371.—Method of plotting Ringelmann readings as suggested by E. J. Bailey. This method consists in finding the total time during the day represented by each density, reduce it to minutes per hour, and add it to the number of minutes corresponding to each higher density. The totals are plotted against the Ringelmann chart numbers, and the curve represents the fraction of time during which each given degree of smoke density has been reached or exceeded. *Bailey* remarks that Ringelmann chart No. 5 includes all smoke that is opaque. Twice as much carbon can be carried at one time as at another, and not affect the density reading.

For these reasons, the temperature in the furnace of a steam boiler rarely, if ever, exceeds 3,000°-F. The temperature rise, then, is equal to the calorific value of the fuel minus the losses due to the foregoing causes divided by the product of the weight of gases times their specific heat.

NOTE.—*Admiral R. T. Hall* describes an electrical means of determining the density of smoke used on the U. S. S. Conyngham. The basic principle is the sensitivity of the metal selenium to light as affecting the passage of electric current. A selenium disc connected to the ship lighting circuit was placed on one side of the stack opposite a light on the other. The intensity of the beam of light striking the disc of course varied with the density of the smoke. A milliammeter with a suitably graduated scale indicated the changes in current due to the changes in smoke density.

Ques. How can an increase in the furnace temperature be obtained?

Ans. 1, By using a coal with a higher heating value; 2, by decreasing the amount of excess air supplied, obtaining more complete combustion; 3, by decreasing the amount of heat radiated from the fuel on the grates, and 4, by preheating the air admitted for combustion.

Ques. What is the effect of increased furnace temperature on the heat absorption and efficiency, and why?

Ans. If all the other conditions be maintained constant but a coal of a higher heating value be substituted, the total heat absorbed and efficiency will be higher since there will be a greater amount of heat absorbed by direct radiation.

If the amount of excess air supplied be decreased to secure better combustion, both the heat absorption and efficiency will be increased.

If the amount of heat radiated from the furnace walls be decreased, both the heat absorption and efficiency are increased, but cut down the amount of heat radiated to the water heating surface and it will be found that both the heat absorption and efficiency are decreased.

Ques. What is the effect of preheating the air supply?

Ans. It increases both the heat absorption and efficiency.

Ques. What difficulties are likely to be encountered in increasing the furnace temperature?

Ans. High furnace temperatures cause increased depreciation of the brickwork and ironwork and is accompanied by the formation of clinkers.

Coal ash becomes plastic or even liquid at certain temperatures, depending on its composition. When these temperatures are reached, the ash will fuse and tend to clog the grates, interfering with the air supply and decreasing the rate and efficiency of combustion. This tendency is increased if, in the manipulation of the fire, the ash be raised to the surface of the fue bed and exposed to the full furnace temperature.

Ques. What determines largely the temperature of combustion?

Ans. The design of the furnace.

The most important features of the design in this respect are the arrangement of brickwork and heating surface, the volume and length of the combustion space and the type of grate or stoker. These items affect the furnace temperature because they control the degree of the completeness of combustion, the amount of radiation and to some extent the amount of air admitted.

Ques. What should be considered in the selection of fire brick for a furnace?

Ans. They should be chosen to meet the operating conditions of load, furnace temperature, and character of coal particularly with respect to the composition of its ash.

For instance, where there is a steady load and the ash of the coal burned does not exert an appreciable fluxing action on the brick, any good grade of fire brick whose fusing temperature is greater than the maximum furnace temperature obtained would be satisfactory, if properly installed and given reasonable care.

Where the fine ash carried through the furnace by the gases exerts a fluxing action on the brick, the brick used in that part of the furnace exposed to this action should be especially chosen for its ability to resist this influence.

In many cases the ash in the fuel bed itself exerts a very destructive effect on the brick work exposed to its influence. Where the load is exceedingly variable and where sudden inrushes of cold air into the furnace cannot be avoided, heavy stresses are set up in the brick, which call for a brick mechanically strong and with a minimum tendency to spall.

Ashes.—By definition the term ashes signifies *all the mineral matter left after the complete combustion of fuel.*

Every variety of mineral fuel contains more or less incombustible matter or ashes.

Ques. Why do fuels contain incombustible matter?

Ans. Because the plants of which the coal is formed contained inorganic matter, and because of the earthy matter in the drift of the coal period.

Ques. What are the principal constituents of ashes?

Ans. Silica, alumina, lime, oxide and bisulphide of iron.

According to Kent the composition of ash approximates that of fine clay, with the addition of ferric oxide, sulphate of lime, magnesia, potash, and phosphoric acid.

White ash coals generally contain less sulphur than the red ash coals, which contain iron pyrites.

The analysis of ashes of Pennsylvania anthracite coal by Professor Johnson yielded:

Silica	53.6
Alumina	36.69
Sesquioxide of iron	5.59
Lime	2.86
Magnesia	1.08
Oxide of magnesia	.19
	100.01

Ohio bituminous coal, containing 5.95 per cent of ash, yielded upon analysis:

Silica	58.75
Alumina	35.3
Sesquioxide of iron	1.2
Magnesia	.68
Potash and soda	1.08
Phosphoric acid	.13
Sulphuric acid	.24
Sulphur combined	.41

Ques. What is clinker?

Ans. A product formed in the furnace by fusing together impurities in the coal such as oxide of iron, silica, lime, etc.

Ques. Which coals clinker least under high temperature, as judged from the color of the ashes?

Ans. Those whose ashes are nearly pure white.

Ques. What substance in ashes causes clinker?

Ans. Oxide of iron.

The presence of oxide of iron in any considerable quantity is indicated by the red color of the ashes. Coals high in sulphur generally give a very fusible ash, on account of the iron with which the sulphur is in combination. A double ash tends to form clinker.

Ques. With complete combustion of coal, what percentage of ashes remain?

Ans. It varies considerably for different coals, but average values will be between 5 and 10 per cent.

CHAPTER 58

FUEL ANALYSIS

Why Tests Should be Made.—The value of coal for the production of heat for any given purpose cannot be ascertained from its appearance. The value is not determined by the locality of the mine from which it is obtained, nor by the trade name by which it is placed on the market.

The final value is determined by the results secured when it is used for the purpose intended. Satisfactory results, however, depend upon two conditions:

1. The quality and nature of the coal must be suited for the work intended.

2. The method of firing or using the coal must be correct.

To use fuel intelligently it is necessary to ascertain these two conditions. The first condition: *the determination of the intrinsic quality of the coal*, can be determined only by a laboratory test. The second condition: *the realization of satisfactory operation*, is obtained, first, as an outcome of the first condition, namely: the obtaining of a fuel with proper constituents; secondly, its proper method of use as determined by practical operating experience, modified according to the quality and properties of the coal as determined by test.

Ques. State the advantages due to testing of fuel.

Ans. 1. It determines its fair purchase price; 2, it locates the difficulty when results are not satisfactory; and, 3, it is a guide to better operation.

Apparatus Required for Fuel Testing

For the Determination of B. T. U.'s, Moisture, Volatile Mater, Ash and Sulphur.

Sampling and Preparation of Laboratory Samples

Crusher
Pulverizer
or Ball Mill
Sampler
Sampling Cloth
Brush
Sieves
Analytical Balance
Set of Weights
Sample Bottles 4 oz. with stoppers
Porcelain Capsules with cover
Mason Jars
Spatula
Pellett Press (Optional)

Moisture

Drying Oven
  If gas, with burner and thermo-regulator
  If electric, Freas or Varsity Electric Oven
Analytical Balance
Set of Weights
Capsules with cover
Dessicator
Calcium Chloride gran.: for dessicator

Ash

Gas Burner with rubber tubing, also
Tripod with triangle
or Gas Furnace
or Electric Furnace
Dessicator
Calcium Chloride gran.: for dessicator
Analytical Balance
Set of weights
Crucible Tongs

Volatile Matter

Platinum Crucible with cover, 10 or 20 gram
Tripod with Nichrome Triangle
Meker Burner No. 3
or Electric Furnace
or Gas Furnace

Sulphur

Porcelain Crucibles No. 1
Muffle Furnace
or Gas Burner with tripod and triangle
Analytical Balance
Set of Weights.
Funnel Stand
Funnels
Filter Paper, ashless
Drying Oven
Beakers
Eschka Mixture
Bromine

B. T. U.'s

Calorimeter
Thermometer
Oxygen

Fusing Point of Coal Ash

"High-Temp" Electric Furnace
or Gas Furnace
Pyrometer

Methods of Testing Coal.—The true test of any coal is the burning of it, but the chemical character and quality of a coal is a reliable indication of what may be expected from its use. Coal can be purchased under specifications as to the chemical content, and knowledge of the chemical content makes it possible to determine whether the coal specified has been delivered.

In a large manufacturing plant coal and cinder analyses should be made daily. Coal testing has become standardized with the following analyses and tests that have been found to give sufficient information as to the value of a given coal and its fitness for a given service.

These analyses and tests are:

1. Proximate analysis; 2, ultimate analysis; 3, sulphur test; 4, heat of combustion (calorimeter) test; 5, ash analysis.

Ques. What is the difference between a *proximate* and an *ultimate* analysis?

Ans. A proximate analysis separates the coal into four parts: moisture, volatile matter, fixed carbon, and ash; and ultimate analysis reduces the constituents of the fuel (except the moisture and ash) to the ultimate chemical elements: carbon, hydrogen, nitrogen, sulphur, and ash.

Ques. Define fixed carbon.

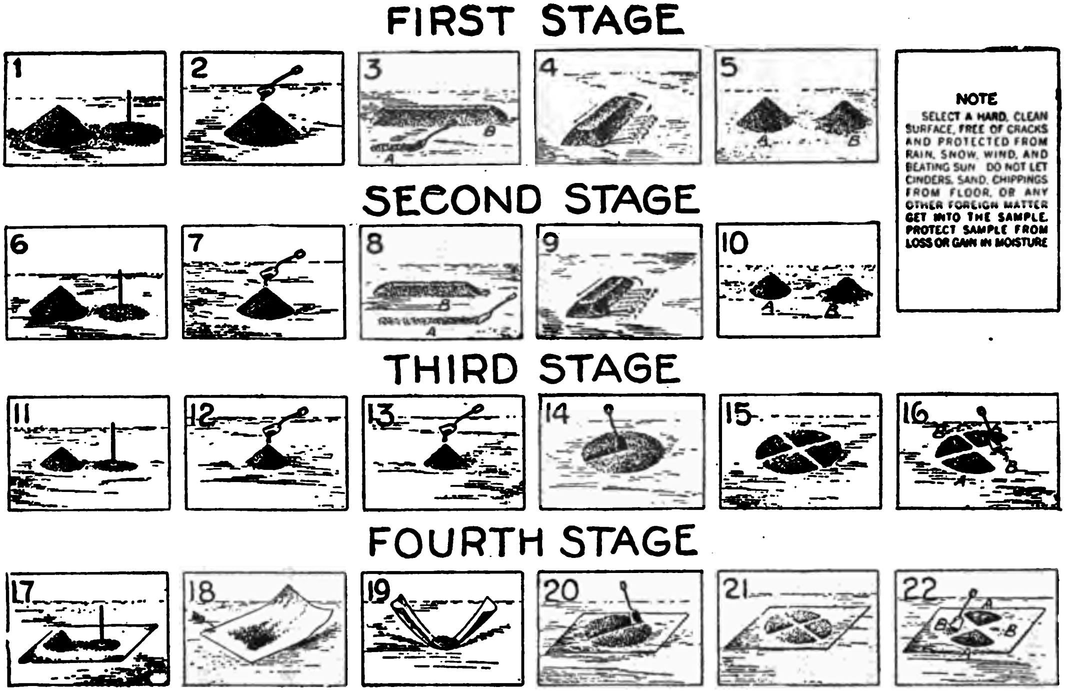
Ans. Fixed carbon is *the carbon remaining* ***after*** *distillation*.

It is *not* the same as the total carbon found by ultimate analysis.

Ques. Define combustible.

Ans. Combustible is *that portion of the coal left after subtracting the ash and moisture*.

Ques. What is volatile matter?



FIRST STAGE

SECOND STAGE

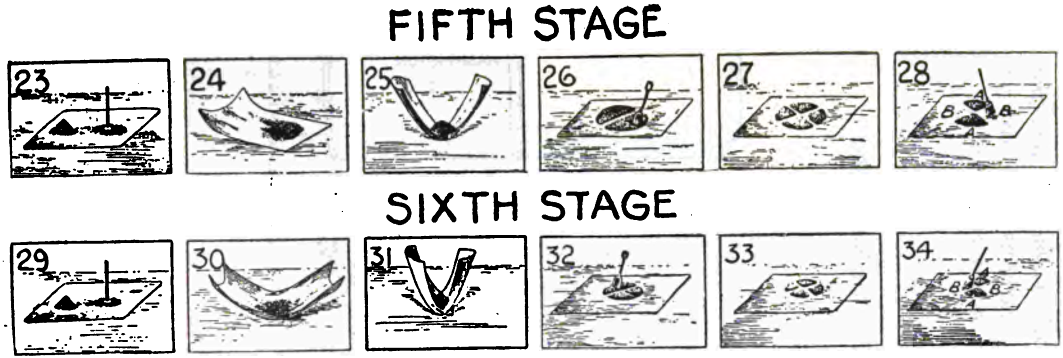
THIRD STAGE

FOURTH STAGE

NOTE

SELECT A HARD, CLEAN SURFACE, FREE OF CRACKS AND PROTECTED FROM RAIN, SNOW, WIND, AND BEATING SUN. DO NOT LET CINDERS, SAND, CHIPPINGS FROM FLOOR, OR ANY OTHER FOREIGN MATTER GET INTO THE SAMPLE. PROTECT SAMPLE FROM LOSS OR GAIN IN MOISTURE

FIGS. 3,372 to 3,405.—Bureau of Mines method of preparing a gross sample of coal by hand. The necessary tools are a shovel, tamper, blanket measuring about 6 X 8 feet, broom, and rake. The coal is raked while being crushed, so that all lumps will be crushed. Floor or blanket is swept clean of discarded coal each time after sample is halved or quartered. ***Collection of gross sample.*** The increments shall be regularly and systematically collected, so that the entire quantity of coal sampled will be



FIGS. 3,372 to 3,405.—*Text continued.*
represented proportionately in the gross sample, and with such frequency that a gross sample of the required amount shall be collected. The standard gross sample shall not be less than 1,000 pounds, except that for slack coal and small sizes of anthracite in which the impurities do not exist in abnormal quantities or in pieces larger than ¾ inch, a gross sample of approximately 500 pounds shall be considered sufficient. If the coal contain an unusual amount of impurities, such as slate, and if the pieces of such impurities be very large, a gross sample of 1,500 pounds or more shall be collected. The gross sample should contain the same proportion of lump coal, fine coal, and impurities as is contained in the coal sampled. When coal is extremely lumpy it is best to break a proportional amount of the lumps before taking the various increments of a sample. Provision should be made for the preservation of the integrity of the sample. ***Quantity represented.*** A gross sample shall be taken for each 500 tons or less, or in case of larger tonnages for such quantities as may be agreed upon. ***To prepare sample:*** 1. Crush 1,000 pound sample on hard clean surface to 1″ size. 2. 1,000 pound sample crushed to 1″ and coned. 3. Mix by forming long pile, *A*, spreading out first shovelful, *B*, long pile completed. 4. Halving by alternate shovel method. Shovelfuls 1, 3, 5 etc. reserved as 5, A; 2, 4, 6 etc. rejected as 5, B. 5. Long pile divided into two parts: A, reserve; B, reject. 6. Crush 500 pound sample (5,A) to ¾″ size. 7. 500 pounds crushed to ¾″ and coned. 8. Mix by forming long pile, *A*, spreading out first shovelful; *B*, long pile completed. 9. Halving by alternate shovel method. Shovelfuls 1, 3, 5 etc. reserved as 10 A; 2, 4, 6 etc. rejected as 10 B. 10. Long pile divided into two parts: A reserve, B reject. 11. Crush 250 pound sample (fig. 10 A) to ½″ size. 12. 250 pounds crushed to ½″ and coned. 13. Mix by forming new cone. 14. Quarter after flattening cone. 15. Sample divided into quarters. 16. Retain opposite quarters *A*. *A*. Reject quarters *B*. *B*. 17. Crush 125 pound sample (16 A. A.) on blanket to ⅔″ size. 18. Mix by rolling on blanket. 19. Form cone after mixing. 20. Quarter after flattening cone. 21. Sample divided into quarters. 22. Retain opposite quarters *A*. *A*. Reject quarters *B*. *B*. 23. Crush 60 pound sample (22 *A*. *A*.) to ¼″ size. 24. Mix by rolling on blanket. 25. Form cone after mixing. 26. Quarter after flattening cone. 27. Sample divided into quarters. 28. Retain opposite quarters A. A. Reject quarters *B*. *B*. 29. Crush 30 pound sample (28 *A*. *A*.) to 3⁄16″ or 4 mesh size. 30. Mix by rolling on blanket. 31. Form cone after mixing. 32. Quarter after flattening cone. 33. Sample divided into quarters. 34. Fill two 5 pound sample containers from *A*. *A*.—one for laboratory, one for reserve.

Ans. Volatile matter is *the total combustible less the fixed carbon*, and includes gases, hydro-carbons, free oxygen and nitrogen, although the latter two are not combustible.

Ques. What is ash?

Ans. Ash is *the residue remaining after the moisture and volatile have been driven off and the fixed carbon ignited.*

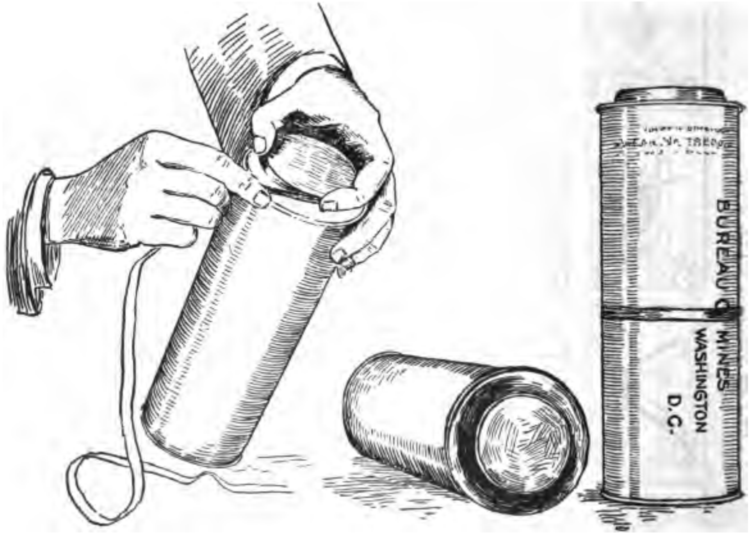


FIG. 3,406 to 3,408.—Method used by Bureau of Mines for sealing shipping can with adhesive tape.

Ques. What is moisture?

Ans. Moisture is the loss in weight of a sample of coal when dried at a given temperature for a given length of time.

Proximate Analysis.—As stated by Kent, the proximate analysis is a most valuable means of identifying the general character of the coal.

1. The amount of combustible matter, expressed as a percentage of the combustible, distinguishes between the anthracite, the semi-bituminous, and the bituminous coals.

2. Among the bituminous coals, the moisture is an important guide to the character of the coal.

3. The ash is also a criterion of the coal's value.

4. The sulphur taken in connection with the ash is also an indicator of the value of the fuel, as high sulphur generally is found in a coal which clinkers badly, and with which it is difficult to obtain the rated capacity of a boiler.

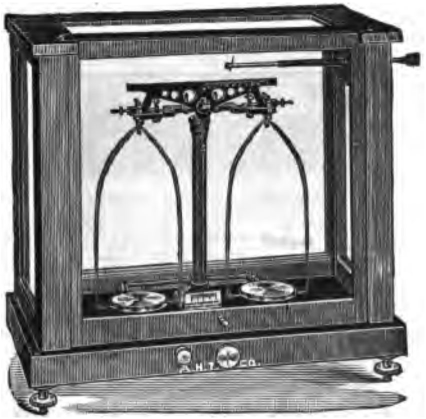


Fig. 3,409.—Gaertner analytical balance designed to meet the requirements of educational laboratories in quantitative analysis, capacity 200 grams, sensibility 1 milligram. The rider is of aluminum, 1 oxidized block, 7 inches long, divided into fifths of milligrams with white divisions. The knife edges and planes are of agate; pans of German silver, 2½ inches in diameter; polished mahogany case with counterpoised front door and base fitted with leveling screws.

Different laboratories use somewhat different methods in making proximate analysis.

Apparatus Required—For making a proximate analysis the following apparatus is required: A mill for grinding the coal, chemical scales sensitive to $^1/_{1000}$ of the amount weighed, drying apparatus, including an oven and a dessicator, a platinum crucible, a Bunsen burner, a blast lamp, and a supply of oxygen. The *Bureau of Mines* prefers sulphuric acid to calcium chloride as a moisture absorbent in the dessicator.

The *U.S. Bureau of Mines* has made a great number of analyses and has developed complete and satisfactory methods which agree very closely with those recommended by the committee on coal analysis of the *American Chemical Society*. The tests of the latter are given to the last detail in the report; they are here briefly given in the larger type as follows:

Moisture.—The moisture content is determined by drying the sample in a suitable oven at a constant temperature of 105° Centigrade for one hour. Upon being removed from the oven the sample should be cooled in a dessicator before weighing.

FIG. 3,410.—Eimer and Amend analytical balance weights. The gram weights are of brass lacquered, the fraction weights of platinum except below 20 milligrams, which are of aluminum. The set includes riders and forceps in mahogany box, hinged lid lined with velvet.

Bureau of Mines Method.—Weigh out 1 gram of the pulverized, air dried sample, and place it in a shallow porcelain capsule, ⅞ inch deep and 1¾ inches in diameter. Dry for one hour at 105° C. in a constant temperature oven, through which a current of preheated air is passing at a rate to change the entire volume of air 2 to 4 times per minute. The air is dried before entering the oven by passing through concentrated sulphuric acid.

After one hour the capsule is removed from the oven, and cooled in the dessicator, the loss in weight is called the *"moisture at 105° C."*

Am. Soc. of M. E. Methods: 25.—When the sample lot of coal has been reduced by quarters to say 100 pounds, a portion weighing say 15 to 25 pounds should be withdrawn for the purpose of immediate moisture determination. This is placed in a shallow iron pan and dried in the hot iron boiler flue for at least 12 hours, being weighed before and after drying on scales reading to quarter ounces.

26.—The moisture thus determined is approximately reliable for anthracite and semi-bituminous coal, but not for coal containing much inherent moisture.

For such coal and for all reliable determinations, the following method should be pursued: Take one of the samples contained in the glass jars, and subject it to a thorough air drying, by spreading it in a thin layer and exposing it for several hours to the atmosphere of a warm room, weighing it before and after, thereby determining the quantity of surface moisture it contains. Then crush the whole of it by running it through an ordinary coffee mill or other suitable crusher adjusted so as to produce somewhat coarse grains (less than 1/16 inch), thoroughly mix the crushed sample, select from it a portion of from 10 to 50 grams, say ⅓ ounce to 2 ounces, weigh it in a balance which will easily show a variation as small as 1 part in 1,000, and dry it for one hour in an air or sand bath at a temperature between 240 and 280° F., (this temperature being necessary with coal which is not powdered). Weigh it and record the loss, then heat and weigh again until the minimum weight has been reached. The difference between the original and the minimum weight is the moisture in the air dried coal. *The sum of the moisture thus found and that of the surface moisture is the total moisture.*

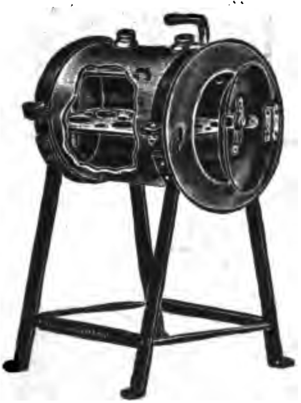


FIG. 3411.—Eimer and Amend double wall oven (*Bureau of Mines type*), designed especially for determining moisture in coal samples. ***It consists of*** a double walled copper cylinder closed at one end and having a double walled door at the other. The space between the two walls is for filling with a solution of glycerine in water (*sp. gr.* 1.19) the proportion being adjusted to maintain 105° C. in the chamber. A copper tube encircles the oven between the walls, and through it is forced a current of air dried by passing through sulphuric acid, which is preheated and forced through the inner chamber, taking up the moisture from the sample and escaping through a small opening in the door of the oven. The chamber is provided with openings for thermometer and gas regulator, and is fitted with a sliding shelf having six holes 1½ inches in diameter to accommodate crucibles. The oven is mounted on a rigid support as shown.

Volatile Matter—The volatile test is made in a platinum crucible with cover. It is accomplished by placing the platinum crucible in a Bunsen flame of proper dimension in a specific position for a certain period of time, weighing the crucible and its contents before and after inserting the same in the flame.

After removing the platinum crucible from the Bunsen flame, it is cooled in a dessicator before weighing. This volatile test can be made by placing the platinum in a furnace, the temperature being gradually raised to 950° C. and maintained. For this work the electric muffle furnace is rapidly becoming the preferred medium.

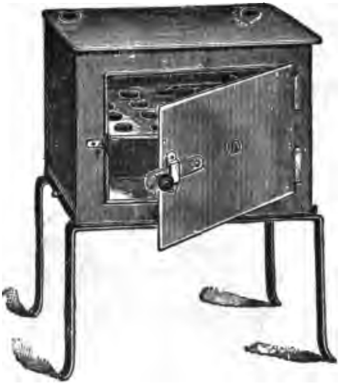


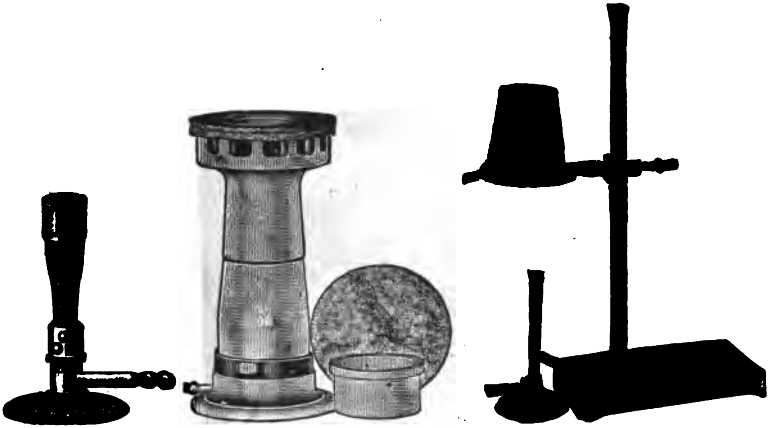
Fig. 3,412.—Gaertner drying oven made of heavy planished copper with tubulation for thermometer and gas regulator, mounted on separate iron support, provided with false bottoms of sheet iron to protect the copper.

Fig. 3,413.—Eimer and Amend multiple unit and electric muffle furnace for use in determining volatile matter. The units form the heating chamber; they are reversible, however, for using either the open groove or closed face. The hinged counter weighted door may be used as a temporary rest for crucibles, etc. The door is reversible for hinging either at bottom or top. A ⅛ inch hole in back provides an escape for fumes, or for the insertion of a pyrometer couple.

Bureau of Mines Method.—One gram of the fine coal (that which passes through a 60 mesh) is weighed into a light, well burnished 10 gram platinum crucible, with a close fitting capsule cover. It is heated to 950° C. or a platinum or michrome triangle for 7 minutes in the full flame of a No. 3 Meker burner.

The flame is 16 or 18 centimeters long, and the bottom of the crucible is 2 centimeters above the top of the burner. A sheet iron chimney is placed around the burner to prevent draught.

The temperature is measured by a thermocouple where hot junction is buried in contact with the coal at the bottom of the crucible. After 7 minutes the crucible is cooled in the dessicator and weighed. *The loss* in weight is the volatile plus moisture.



FIGS. 3,414 to 3,416.—Various laboratory burners. Fig. 3,414, ***meter burner;*** it requires a reasonable gas pressure for most economical operation. The whole flame is practically a homogeneous mass of burning gas, its temperature being nearly uniform throughout; fig. 3,415 ***Chaddock burner,*** it is being incorrodably made of porcelain and white fire clay and is specially adapted for use in hoods where metal burners soon corrode. The burner is supplied with flame spreader, asbestos disc, asbestos ring, and a small chimney for platinum triangles; fig. 3,416 ***Parr blast.*** It yields a flame of high temperature as required for ash and volatile matter determinations.

Am. Soc. of M. E. Method: 274.—Place one gram of the air dried powdered coal in the crucible and heat in a drying oven to 220° F. for one hour (or longer if necessary to obtain minimum weight), cool in a dessicator and weigh.

Cover the crucible with a loose platinum plate. Heat 7 minutes with a Bunsen burner giving a 6 to 8 inch flame, the crucible being supported 3 inches above the top of the burner tube and protected from outside air currents by a cylindrical asbestos chimney 3 inches in diameter.

Cool in a dessicator, remove the cover and weigh. *The loss in weight represents the volatile matter.*

Ash.—Next to the heating value, the ash content is the most important factor in the commercial valuation of coal. The test is made by burning a sample to a constant weight over burners or in a suitable furnace until the ash remaining reaches a constant weight. Chaddock gas burners, small muffle furnaces or small crucible furnaces, either gas or electrically heated, are suitable for this work.

Bureau of Mines Method.—The same sample is used on which the moisture determination was made. It is left in the capsule and placed in a cool muffle. The temperature is gradually raised to 750° C., and the ignition is continued, with occasional showing of the ash, until all the carbon particles have disappeared.

The capsule is cooled in a dessicator, weighed, and the ignition repeated until a constant weight has been obtained. A constant weight is assumed to have been obtained when the difference between successive weighings is .0005 gram.

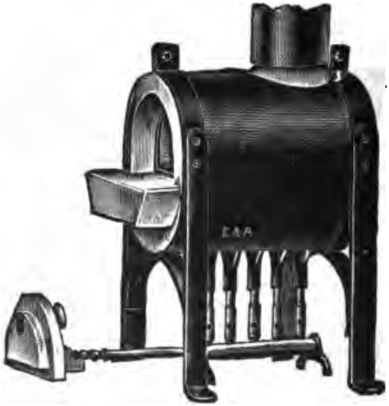


FIG. 3,417.—Weisnegg's muffle furnace for ash determinations, etc. This furnace burns about 20 cubic feet of gas per hour, and will produce a temperature up to about 700° C. Accommodates muffle, $7\frac{3}{16} \times 4\frac{3}{4} \times 2\frac{1}{8}$.

The residue in the capsule represents ***ignited mineral residue or uncorrected ash.***

For technical purposes, the uncorrected ash is reported as determined. The principal use of corrected ash values is in computing the actual coal substance or combustible matter of coal, for comparing ultimate analysis and heating values on this basis.

Am. Soc. of M. E. Method.—Expose the residue in the crucible to the blast lamp until it is completely burned, using a stream of oxygen if desired to hasten the process. *The* ***residue*** *left is the* ***ash.***

Fixed Carbon.—The fixed carbon in coal is determined by the difference in weight from the other three factors of the proximate analysis, *i. e.*, the sum of the percentages of moisture, volatile matter, and ash is deducted from 100%; the remainder is the percentage of fixed carbon.

Bureau of Mines Method.—The fixed carbon is determined by subtracting the sum of the percentages of moisture, ash, and volatile matter from 100.

Am. Soc. of M. E. Method.—The fixed carbon is taken as the difference between the residue left after the expulsion of the volatile matter and the ash.

Sulphur—The sulphur test is made either by direct determination from the sample of coal by the Eschka method, or it is determined from the washings of the bomb calorimeter at the time of making a heat of combustion test.

Bureau of Mines Method.—For the sulphur test use is made of the residue in the calorimeter after completing combustion in the heat of combustion test. The crucible is washed out thoroughly and the washings collected in a 250 cubic centimeter breaker. The washings are titrated with a standard ammonium hydroxide solution to obtain the acid correction for the heating value. Four cubic centimeters of strong ammonium hydroxide are added to insure complete precipitation of any metals in solution, and the solution is heated to the boiling point on the hot plate.

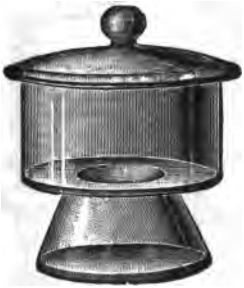


FIG. 3,418.—Scheibler dessicator of Bohemian glass having a ground air tight cover.

The residue mostly ash, is filtered off, and washed five times with hot water, and 5 cubic centimeters of concentrated hydrochloric acid.

A few drops of bromine water are added to the solution which is replaced on the hot plate and heated to the boiling point. Add 10 cubic centimeters of hot 10% barium chloride solution and allow the precipitate to settle for at least 2 hours. The supernatant liquid is decanted and tested with dilute sulphuric acid for an excess of barium chloride. The precipitated barium chloride is collected on a small filter paper and washed with hot water till the washings show no reaction for chloride. The filter paper, with the precipitate, is placed in a crucible, dried, ignited and weighed.

The ignition is in a muffle for 10 minutes. It is covered and cooled in a dessicator. The precipitate is then brushed onto a balanced watch glass and weighed. The sulphur in barium sulphate is $32.07 \div 233.44 = .137$ times the weight of the latter.

The percentage of sulphur can be easily determined from the original weight of coal.

Am. Soc. of M. E. Method.—Use is made of Eschkas method described later.

Eschkas Method.—To deliver sulphur by this method (which is the one commonly used) a sample of 60 mesh coal weighing 1.3736 grams is mixed in a 33 cubic centimeter platinum crucible with about 2 grams of Eschkas mixture (2 pails light calcined magnesium oxide, 1 part anhydrous sodium carbonate), and about 1 gram of the Eschkas mixture is spread over it as a cover.

The mixture is carefully burned out over a gradually increasing alcohol or natural gas flame. When all black particles are burned out the crucible is cooled, the contents digested with hot water, filtered, washed, and the solution heated with salonated bromine water and hydrochloric acid, boiled, and the sulphur precipitated as barium sulphate by adding a solution of barium chloride.

For further particulars see Technical Paper No. 8, 1913 of the *Bureau of Mines.*

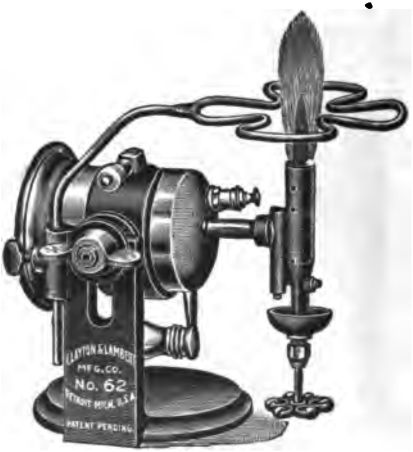


FIG. 3,419.—Clayton and Lambert laboratory blast torch outfit. The adjustable stand permits the flame to be pointed in any position desired. The tripod is also adjustable and will hold any ordinary size pan or laboratory vessel; it can be swung out of the way when not in use.

Ultimate Analysis.—The ultimate analysis of coal for its absolute chemical constituents is a complicated process and one difficult to be carried out; requiring considerable chemical apparatus. It should therefore be attempted only by a chemist or one skilled in making chemical analyses.

NOTE.—A proximate analysis depends upon more or less arbitrary standardized methods which, if not rigidly followed, give different results for the same coal sample. This analysis, however, is an acceptable indicator of the *type* of coal.

In the ultimate analysis, the chemical elements are determined without regard to their combinations. Greater accuracy of determination is possible than with the proximate analysis. The items considered in an ultimate analysis are: moisture, carbon, hydrogen, oxygen, sulphur, nitrogen and ash.

The ultimate analysis is used in *classifying* coals, and to calculate the heating value of a coal in the absence of a calorimetric determination.

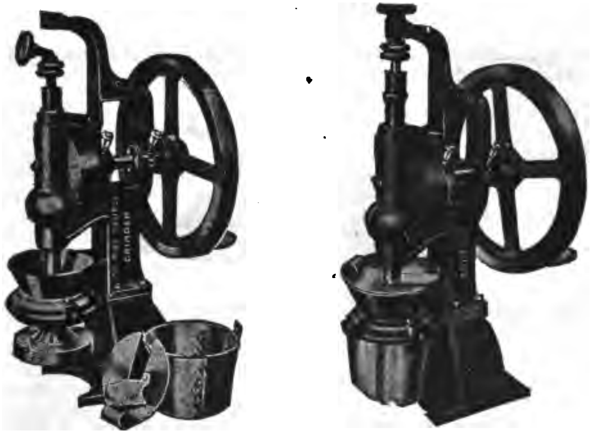


FIG. 3,420 and 3,421.—Braun hand power coal grinder fitted with special discs for quickly reducing coal and coke samples to the fine mesh required for coal analysis and calorimeter determinations.

The sulphur determination is made in connection with a proximate analysis and is used to check up coal deliveries with specifications.

An ultimate analysis does not distinguish between carbon and hydrogen derived from the organic or combustible matter of the coal and the small proportion of these elements that may be present in an incombustible form in the mineral impurities. Since the error is small a correction is not necessary.

An ultimate analysis includes the hydrogen and oxygen of the moisture with the hydrogen and oxygen of the dry substance. Usually before comparisons are made, the ultimate analyses are computed to a dry coal basis, thus giving the relative proportions of hydrogen and oxygen in the coal after the moisture has been eliminated.

Apparatus required.—Mill or grinder for pulverizing the coal; chemical scales; drying apparatus; combustion apparatus containing a combustion furnace, glass combustion tube, one end of which is filled with copper oxide and chromate of lead and the other end with a roll of oxidized copper gauze; a porcelain boat; set of bulbs containing hydrate of potassium; a tube filled with chloride of calcium; a supply of pure oxygen and pure air, together with suitable chemicals and chemical apparatus required for the various processes.

MOISTURE

The methods employed by the *Bureau of Mines* and *Am. Soc. of M. E.* are the same as described under *proximate analysis*.

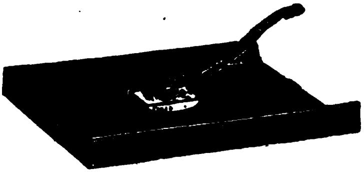


FIG. 3,422.—Crusher plate made of chilled iron with rim, for powdering coal, etc.; with rubber set in wooden handle.

CARBON AND HYDROGEN

Bureau of Mines Method.—2 grams of air dried coal is burned in a 25 burner Glaser furnace of Heraeus electric furnace. Complete oxidation is insured by passing the products of combustion over red hot copper oxide. A layer of lead chromate follows the copper oxide to remove the sulphur.

The water vapor and carbon dioxide are absorbed and weighed in previously weighed calcium chloride and potassium hydroxide solutions respectively.

No correction is made for the carbon or hydrogen from inorganic matter in the coal.

Am. Soc. of M. E. Method.—½ gram of the pulverized oven dried coal is placed in a porcelain boat, which is introduced between the copper roll and the copper oxide within the combustion tube. After the contents within have been thoroughly dried out by a sufficient preliminary heating, aided by a current of dry air, the furnace is set to work and the coal burned by passing air through the tube, and then finally oxygen, conducting the products of combustion through the potash bulb and the chloride of calcium tube.

The carbon dioxide is absorbed by the potash and the water for the combustion of hydrogen is taken up by the calcium chloride. The quantity of carbon dioxide, from which the carbon is determined, is ascertained from the weight of the bulb before and after the absorption.

The quantity of hydrogen is determined by weighing the calcium tube before and after, which gives the amount of water produced, and, dividing by 9, the amount of hydrogen.

NITROGEN

Bureau of Mines Method.—For nitrogen determination the *Bureau of Mines* uses the Kjeldahl-Grenning method, which is as follows: 1 gram of air-dried coal is digested with 30 *cc*. of concentrated sulphuric acid, ½ gram of metallic mercury and 5 grams of potassium sulphate, until the carbon has been completely oxidized and nitrogen converted to ammonium sulphate. After dilution with water and precipitation of the mercury by the addition of potassium sulphate, an excess of sodium hydroxide is added, and the ammonia is determined by distillation.

Am. Soc. of M. E. Method.—Mix a certain weight of coal with stray sulphuric acid and permanganate of potash and heat until nearly colorless. This process converts the nitrogen into ammonia and then into sulphate of ammonia, and the amount of sulphate is determined by making the solution alkaline and then distilling it. The nitrogen is found by calculation from the known composition of ammonia.[†]

SULPHUR

The methods employed by the *Bureau of Mines* and *Am. Soc. of M. E.* are the same as described under *proximate analysis*.

NOTE.—A complete description of this method is given in the *Bureau of Mines* Technical Paper No. 8.

[†] NOTE.—Recent experiments show that the nitrogen thus found in coal is .2 to .3% too low, and that in order to obtain more accurate results it is necessary to add mercury and potassium sulphate. See paper by Fieldner and Taylor in *Jour. Ind. and Eng. Chem.*, Feb., 1915.

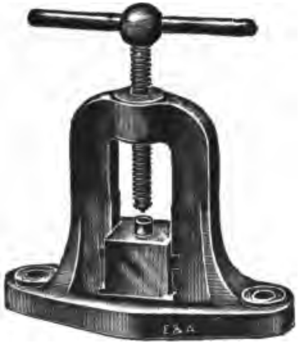
ASH

The same methods are used as described under ***proximate analyses.***

Am. Soc. of M. E. Method.—The ash is found by weighing the refuse left in the combustion boat after the coal is completely burned.

OXYGEN

The oxygen is the difference between the sum of the elements previously determined and the original weight of the coal.



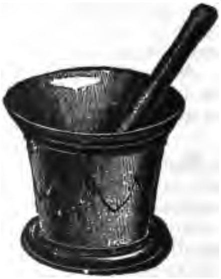


FIG. 3,423.—Pellet press for preparing pellets of coal for the calorimeter test.

FIG. 3,424.—Bell shape mortar with pestle.

Heating Value for the Ultimate Analysis.—The heating value can be obtained from an ultimate analysis by substituting in Du Longs formula, which is:

$$\left.\begin{array}{c}\text{Heating value or } \textit{B.t.u.}\\ \text{per pound of coal}\end{array}\right\} 14{,}544\,C + 62{,}028\left(H - \frac{O}{8}\right) + 4{,}050\,S$$

in which C, H, O, and S, are respectively the percentages of carbon, hydrogen, oxygen and sulphur in the combustible.

Ques. Why is this method objectionable?

Ans. 1, the heating value of the several elements have not been accurately determined; 2, the heating value of the elements in a free state is not necessarily the same as when they are component parts of a chemical compound; 3, the assertion that all the hydrogen is combined with the oxygen is not correct; 4, the relative accuracy is subject to the uncertainty of the oxygen determination, and 5, high cost of making an ultimate analysis.

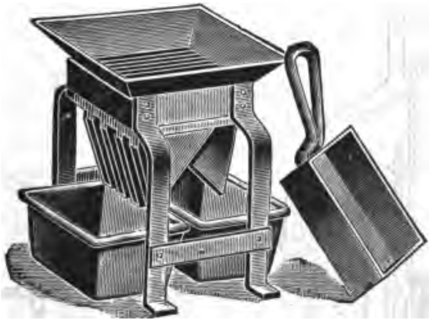


Fig. 3,425.—Jones coal sampler. It consists of a hopper set in a four legged support, scoop and form sampling pans and brush.

For low grade Western coals, in which approximately only two thirds of the oxygen is in combination with the carbon, Du Long's formula would give heat values too low by assuring that all the oxygen is in combination with the hydrogen.

Heat of Combustion of Calorimeter Test.—Since the amount of water evaporated per pound of coal burned under a boiler does not of itself indicate the efficiency of the boiler, it is necessary to know the heating value of the coal used.

For instance, an equivalent evaporation of 8 pounds of water per pound of dry coal represents an efficiency of 70½% if the coal contained 11,000 *B.t.u.* per pound, but the same evaporation with a coal of say 14,500 *B.t.u.* heating value would represent only 53½% efficiency.

Ques. What kind of heating value is obtained by a calorimeter test?

Ans. The higher heating value.

So called because it is ***higher*** than that obtained under boiler conditions

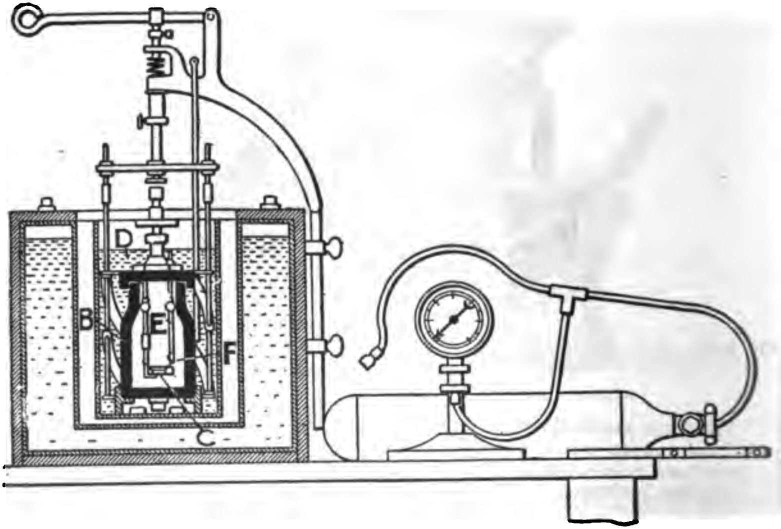


FIG. 3,426.—Mahler calorimeter. ***It consists of*** a steel shell B, with cover, capable of withstanding a pressure 50 atmospheres. The capacity is about 40 cubic inches and the weight 9 pounds. The interior is lined with a coating of enamel to resist corrosion and it is nickel plated on the outside. In the cap is a tube with a stop cock, through which runs a well insulated electrode with a platinum wire on the inner end. The second platinum wire of the circuit supports a small disc on which the fuel to be burned is placed. The vessel holds about 5 pounds of water and is made of thin brass of size to hold the bomb immersed. A screw agitator works outside the bomb to bring all water to the same temperature and a finely divided thermometer is placed in the water. Outside the calorimeter shell is a layer of insulating material and sometimes the whole apparatus is enclosed in another vessel containing water to absorb radiation.

by an amount equal to the latent heat of vaporization of the water formed by the combustion of the hydrogen. The heating value obtained under boiler conditions is called the *lower* heating value.

The higher value is the only scientific unit, and its use is recommended by the A.S.M.E.

Ques. Is there any absolute measure of the lower heating values?

Ans. No.

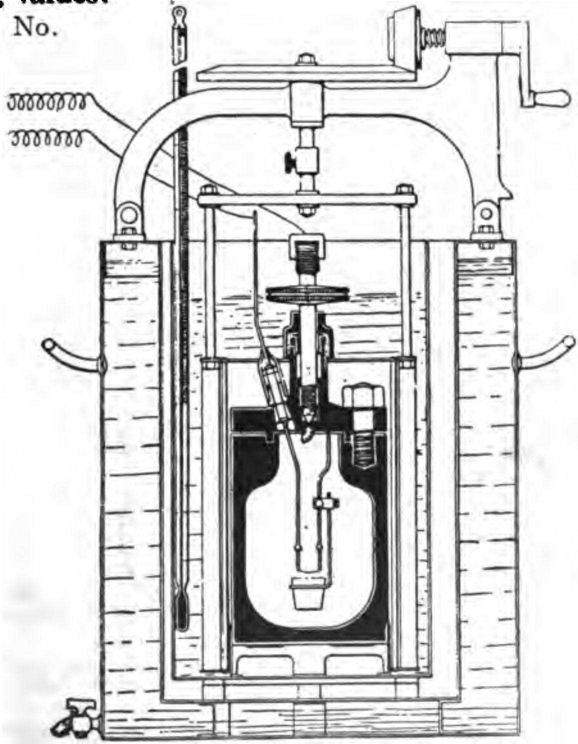
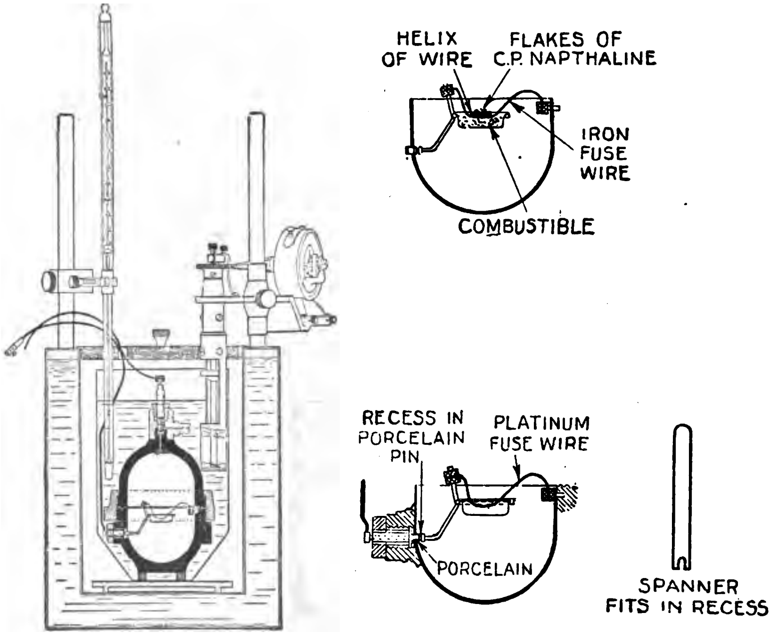


Fig. 3,427.—Sarco calorimeter. ***In construction,*** the bomb is of special metal which resists corrosion and is gold plated on the inside and finished with a coating of platinum. It is fitted with a cover fastened down by three studs and nuts, the joint between the body of the bomb and the cover being made with thin lead wire. The cover has a screw valve attached, which regulates the introduction of compressed oxygen from an ordinary gas cylinder. The electrodes to convey the current are connected by a fine wire which serves to ignite the fuel, when connected with a battery. One of the electrodes is insulated by a porcelain collar where it passes through the cover of the bomb.

It is an artificial unit, which involves the ultimate analysis and assumption that make the unit impractical.

Ques. Of what does a standard calorimeter outfit consist?



FIGS. 3,428 to 3,431.—Emerson calorimeter and methods of ignition wiring; fig. 3,429, wiring for coals; fig. 3,430 wiring for low combustibles, standardization; fig. 3,431, spanner. fits in recess.

Ans. It comprises a platinum lined steel cup or *bomb*, closed with a screw cap, and fitted with an oxygen valve, electrodes for electric ignition of the charge, a metal can for holding distilled water, a mechanical device for stirring the water. a thermometer which can be read accurately to .001° C. by means of a cathetometer, and a double walled felt lagged metal jacket containing water in which the can containing the bomb fits.

Ques. Describe how a calorimeter test is made.

Ans. Weigh into a platinum tray 1 gram of the coal sample

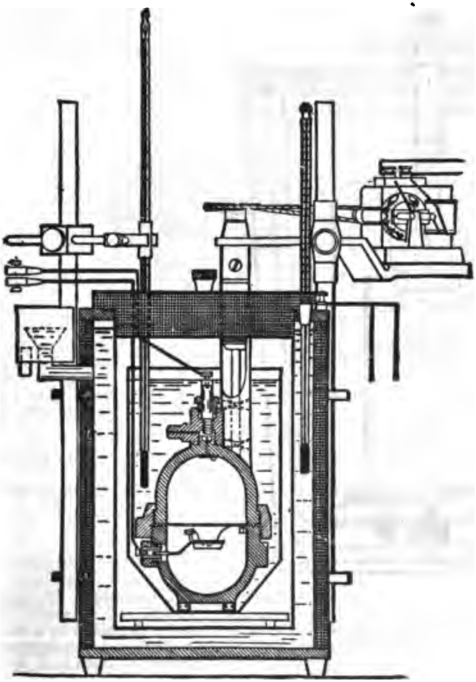


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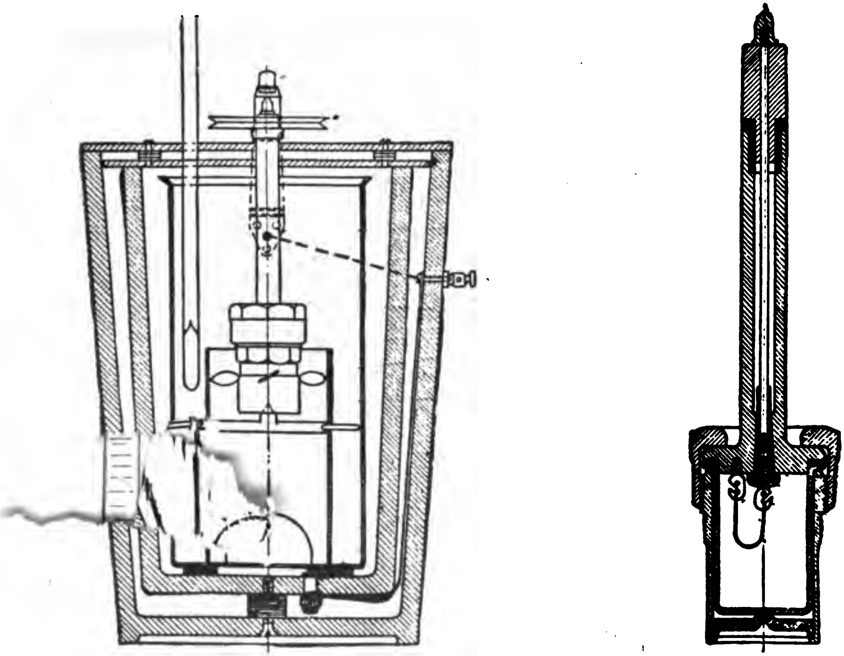
FIG. 3,432.—Emerson calorimeter equipped with vacuum walled jacket. By means of this vacuum cup the radiations to and from the calorimeter water are minimized to such an extent that, at the time of a heat of combustion determination in the calorimeter, the heat reaction is carried out under practically adiabatic condition. This adiabatic condition is most nearly realized during a calorimetric test if the temperature of the calorimeter water be brought into proximity of the temperature of the surroundings in the same manner as with the usual water jacket type of calorimeter. The vacuum wall jacket greatly reduces the radiations from the calorimeter at any temperature, but if the test be attempted at a temperature too remote from room temperature, the radiations may become appreciable and thereby necessitate the computation of the cooling correction.

and place it on the support inside of the bomb. Connect a piece of platinum fine wire to the electrodes and allow it to dip into the coal. After screwing into place the bomb cap admit oxygen to a pressure of 350 pounds. The bomb is now placed in the weighed water, and the temperature of the calorimeter observed at minute intervals for five minutes; at the end of the fifth minute the electric current is closed igniting the coal. The thermometer is now read. The first two readings



Figs. 3,433 and 3,434.—Parr calorimeter and detail of cartridge. Oxygen under pressure is not used. *In testing,* a weighed quantity of coal with the necessary chemicals *thoroughly mixed* is put into the cartridge which is then closed and placed in a measured quantity of water in the can. After the stirrer has been set in motion and constant temperature obtained the coal is ignited. Extracting if the heat be complete in from four to five minutes. The calculation is much in the usual way.

after firing are taken at half minute intervals. Three more readings are taken at minute intervals. The maximum temperature will now have been reached and the thermometer is read for five more minutes.

Ques. How is the heating value of the coal calculated?

Ans. After obtaining the data from the test, connections must be made for the nitrogen content burned to nitric acid, and for the sulphur content burned to sulphuric acid. The net heating value is obtained by multiplying the rise of temperature caused by the combustion of the coal by the water value of the calorimeter.

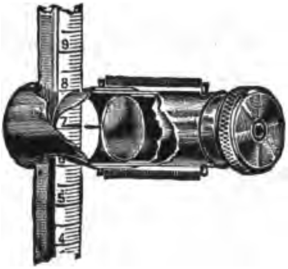


FIG. 3,435.—Eimer and Amend reading lens for reading the divisions on the thermometer. It maintains the same angle of vision for all points on the scale, thus avoiding errors of the parallax, while a magnification is provided which augments the comfort as well as the accuracy of the readings.

Let w = weight of fuel tested in grams.
W_1 = weight of water in calorimetric vessel in grams.
W_2 = water equivalent of calorimeter in grams.
t_0 = temperature C. of water in calorimeter vessel *before* combustion.
t_1 = maximum temperature C. of water in calorimetric vessel *after* combustion.
r = correction coefficient for rise of temperature.
x = heat generated in burning the fuse wire.
y = heat due to the formation of aqueous nitric acid.
z = heat due to the combustion of sulphur to sulphuric acid.
1.8 = coefficient to convert heat of combustion for kilogram-calories per kilogram to *B.t.u.* per pound.

$$\left.\begin{array}{l}\text{Heating value or } B.t.u.\\ \text{per pound of fuel}\end{array}\right\} = \frac{(W_1+W_2) \text{ x } (t_1-t_0)\ r-(x+y+z)}{w}\times 1.8$$

Radiation (*r*) ***correction.***—Pfaundler's method considered most accurate. It assumes that in starting with an initial rate of radiation and ending with a final rate, the rates at intermediate temperatures are proportional to the initial and final rates, that in the rate of radiation at a point midway between the temperature of ignition and the temperature at which combustion is presumably completed will be the means of the initial and final rate. The rate at a point three quarters of the distance on the curve between the two temperatures will be the rate at the lower or initial rate plus three-quarters the difference between the initial and final rate.

****Fuse wire*** (*x*) ***correction.***—For the fuse wire correction multiply its

Emerson Fuel Calorimeter.

Heat of Combustion.

SAMPLE RUN

November 20, 1912.
Run No. 2

Sample No. 128 (air dried.)
Thermometer used, No. 2295.
Weight of tube and coal = 7.9379
Weight of tube = 7.0713
Weight of fuel .8666 grams
Weight of water 1900 grams

Room Temp. = 22° C.

READINGS OF THERMOMETER

Time	Temp.	Time	Temp.	Time	Temp.
0	20.348	6	22.600	10	23.194
1	20.352	30	22.900	11	23.182
2	20.358	7	23.100	12	23.174
3	20.362	30	23.150	13	23.166
4	20.368	8	23.194	14	23.158
5	20.376 Firing Temp.	30	23.196 Max. Temp.	15	23.150
30	21.000	9	23.196		
		30	23.194		

(Calibration Correction)

Temperature at firing = 20.376 + (—.011) = 20.365
Temperature at max. = 23.196 + (+ .002) = 23.198
Rise in temperature corrected for errors in the thermometer = 2.833
Rate of change of temperature before firing — 0.0056 = R1
Rate of change of temperature after maximum temperature = 0.0088 = R2*
Total cooling correction =

$$\text{Total cooling correction} = \frac{(-.0056)}{2} \times (1) + \frac{(+.0088)}{2} \times (2.5) = .008 \text{ (additive)}$$

Total corrected rise in temperature = 2.841
Rise per gram of sample = 3.278
The water equivalent of bomb, calorimeter can, stirrer, etc. = 490
Gram calories per gram of coal = (1900 + 490) 3.278 = 7834
British Thermal Units per pound of coal = 7834 × 1.8 = 14.100

* Rate for last five minutes.
The above are Centigrade temperatures.

weight in milligrams by 1.6, which is the number of calories per milligram. The result is in given calories.

***Nitric acid** (*y*) **correction.**—The bomb is carefully washed with water. The washings are titrated with standard ammonia solution (containing .00587 grams of NH_3 per *cc.*). The correction is 5 gram calories per *cc.* of the ammonia solution.

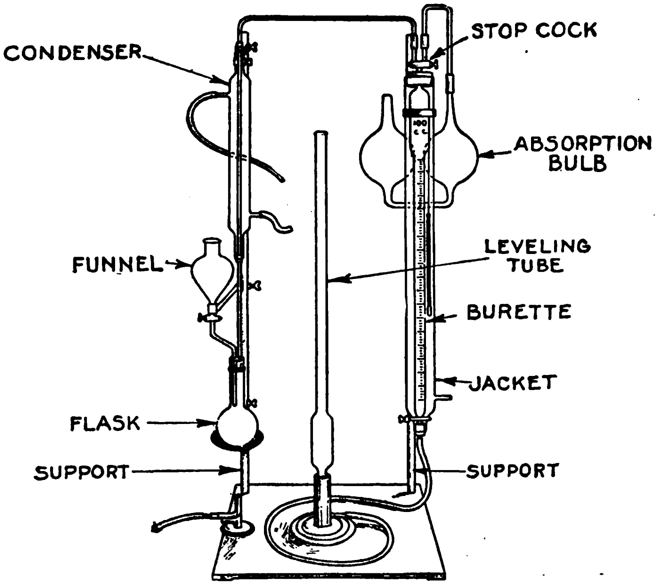


FIG. 3,436.—Apparatus for determination of total carbon for use in connection with Parr calorimeter. ***Operation:*** The fused material is brought into the flask, and dissolved with the washings from the interior of the bomb. By admitting acid from the funnel, the carbon dioxide is liberated and carried over into the jacketed burette. In this condition, also, the temperature may be read by means of the thermometer suspended in the water surrounding the burette. The gas thus measured, which may also have a small admixture of air, is conducted over into the absorption bulb, in which is contained a solution of caustic potash for absorbing the CO_2. Upon releasing the residual gas to the burette, and reading the volume, the dimensions indicates the volume of carbon dioxide present at the outset. The apparatus permits of boiling the liquid in the flask in order to expel the dissolved gases, and, by means of the condenser, the gas is handled at a constant temperature.

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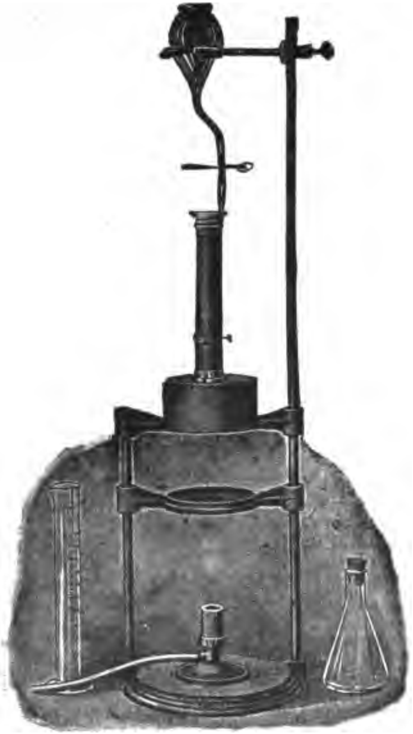
*NOTE.—Detailed instructions for making corrections and calculations are given in the *Bureau of Mines'* technical paper No. 8.

*NOTE.—For the derivation of the correction figures and other details, see *U. S. Bureau of Mines'* technical paper No. 8, 1913.

Sulphur** (s) **correction.—This correction, which is obtained by precipitation as barium sulphate, is 13 gram calories per .01 gram of sulphur.

Ques. What is the water equivalent of a calorimeter?



Ans. It is the heat capacity of the apparatus referred to water as unity; that is, the sum of the product of three weights of the parts by their several specific heats.

Methods of obtaining the water equivalent.

1. By burning in the calorimeter a known weight of a substance, the heating value of which is accurately known, and calculating the water equivalent by the heat difference. This method used by the *Bureau of Mines* because of its convenient application.
2. By the method of mixtures.
3. By introducing electrically into the calorimeter a known quantity of heat.
4. By burning in the calorimeter the same weight of a given substance but using

FIG. 3,437.—Eimer and Amend sulphur photometer for use in conjunction with Parr calorimeter. The fusion of coal, coke, petroleum, etc., by means of sodium per-oxide as carried out in the Parr calorimeter, is made use of for determining sulphur. ***Operation:*** Upon removal of the fused mass, it is dissolved in water and made slightly acid with pure hydrochloric acid. An aliquot part of this solution is taken and made up to 100 *cc.* and transferred to an Erlenmeyer flask. To this, at room temperature is added a large crystal of barium chloride and at once the flask is shaken vigorously for a short time. The turbid solution is then ready to read in the photometer.The liquid containing the purely divided precipitate of barium sulphate is poured into the dropping funnel F, and gradually admitted through the pump cock C, into the graduated tube A. The lens effect at the bottom of the tube is obtained by immersing the same in water. By noting the depth at which the light from the flame disappears a reading is obtained directly which indicates the percentage of sulphur in the sample under examination.

different amounts of water; these equations may be results involving two unknown quantities, namely, the water equivalent and the heating value of the substance.

5. By weighing the parts and adding the products of the weights by the specific heats.

Ash Analysis.—According to the method employed by the Bureau of Mines, ash is determined in the residue of dried coal from the moisture determination the porcelain capsule containing this residue is placed in a muffle furnace and slowly heated until the volatile matter in the coal is driven off.

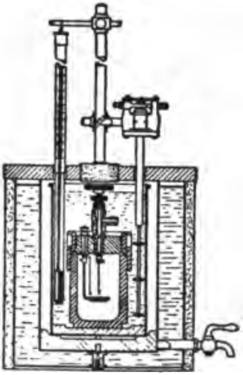


FIG. 3,438.—Scientia calorimeter. It is of the Berthelot type. The steel bomb is 2¼ inches in diameter by 3¾ inches high; ⅜-inch wall; porcelain lining on inside. The cover of the bomb of the regular outfit has a needle valve with a screw connection for the oxygen inlet and is also provided with an insulated electrode to which one terminal of the electric circuit for igniting the charge is connected. The other side of the electric circuit does not require an insulated electrode, but can be attached to any point on the lid of the bomb. If it be desired to displace the products of combustion after the test, in order to analyze them for certain constituents such as CO_2 for example, the bomb can be fitted with two needle valves and screw connections, one of which fitted with a platinum tube running to the bottom of the bomb. This furnishes a convenient and accurate method for determining the carbon in the sample tested, and gives an opoprtunity of forcing the air from the bomb before filling it with compressed oxygen. This calorimeter is also made with vacuum insulation.

The object of the slow heating is to avoid coking the sample and thus making its burning difficult; furthermore, if a coal that is high in volatile matter be rapidly heated, the gas generated has a tendency to explode within the capsule and thus carry off mechanically portions of the ash.

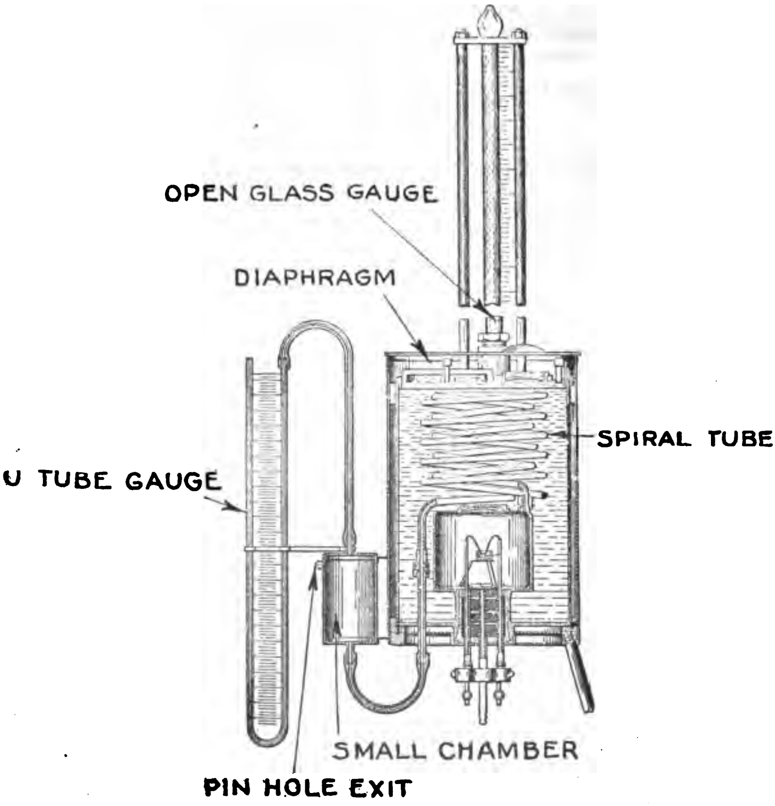


FIG. 3,439.—Carpenter calorimeter. It differs from other calorimeters in that provision is made in the apparatus for giving the heating value of the fuel almost direct in *B.t.u.*, dispensing also with some of the objectionable features, such as errors involved in the thermometer, the determination of the water equivalent, correction for evaporation, radiation, and specific heats. ***In principle,*** the calorimeter in a large thermometer, in the bulb of which combustion takes place, the heat being absorbed by the liquid which is with the bulb. The absorption of heat is proportional to the height to which a column of liquid rises in the attached glass tube. ***In operation,*** the products of combustion pass upward and downward through the spiral tube to the small chamber which is connected on the outer end with an open U tube gauge. The water in the chamber surrounding the combustion cylinder forms a bath which is connected with an open glass gauge above the water chamber. A diaphragm above the water is used to adjust the level. From the small chamber, a pin hole exit, serves to allow the products of combustion to escape slowly. Five pounds of water are placed in the bath and the charge of fuel used is 2 grams. The asbestos cup is heated to drive off all organic matter. This cup is then weighed, the sample placed in it and the whole weighed

The ignition in the muffle is continued at a temperature of about 750°C., with occasional stirring of the ash, until all particles of carbon have disappeared. The capsule with its contents is then taken from the muffle, cooled in a desiccator, and weighed, after which it is replaced in the muffle, heated for half an hour, cooled in a desiccator, and weighed again.

If the change in weight be less than .0005 gram (if the change be greater than this, the ash is again ignited for 30 minutes and the process is repeated until the variation in weight between two successive ignitions is .0005 gram or less), the weight is considered as constant and the weight of the capsule is deducted from the last weighing.

The weight of the capsule and ash minus the weight of the capsule is taken as the weight of the ash.

In the case of coals high in iron, some difficulty is often experienced in ignition to constant weight, because of the oxidation and reduction of iron oxides.

Ash as determined by this method represents the mineral matter that remains in coal after ignition.

Analysis of Liquid Fuels.—The determination of carbon and hydrogen in liquid fuels is made in the same manner as that concerning the solid fuels, using special means for preventing loss in the various processes on account of the volatile characteristics of the fuel. The ultimate analysis of liquid fuel like that of

FIG. 3,439.—*Text continued.*

together. The difference gives the weight of the coal used for the test. The cup is then placed in proper position on the bottom plug, which is inserted in the combustion cylinder. Raise the ignition wire above the coal, turn on the current which will, of course, heat the air in the cylinder and cause the water to rise slightly in the glass tube. As soon as this commences, turn on the oxygen and pull down the ignition wire to kindle the coal, at the same instant taking the reading on the glass scale. When combustion has finished as determined by looking through the observation windows, the scale reading and the time should be taken. The difference between the first and last readings taken will be the actual scale reading. This must be corrected for radiation.* The amount of ash is determined by weighing the asbestos cup after combustion. Dividing the *B.t.u.* developed during the test by the weight of coal burned in pounds gives the *B.t.u.* per pound. For ordinary everyday work this is one of the most convenient pieces of apparatus that has been devised, but does not show quite as accurate results in use as the Mahler.

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*NOTE.—To make this correction let the apparatus stand with the oxygen shut off as long as it took for the combustion to take place, then take the scale reading and the time. It is assumed that the drop in the scale reading during this time will indicate the amount of the radiation which took place during the combustion, and should, therefore, be added to the actual scale reading to give the corrected reading. With each calorimeter is furnished a calibration curve from which by comparison with the corrected scale reading the *B.t.u.* developed during the combustion can be found.

coal, should only be undertaken by a person familiar with all the necessary details.

Ques. How is the sulphur test made?

Ans. The oil or other liquid is heated with nitric acid and barium chloride. The quantity of sulphate of barium thus produced is ascertained by filtering and weighing, and the sulphur calculated from the known composition of the compound.

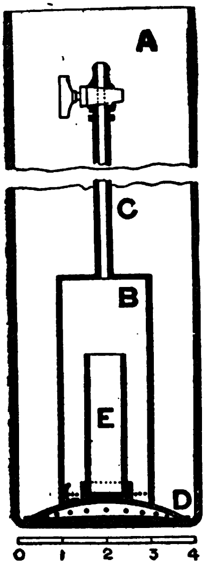

FIG. 3,440.—Thompson calorimeter. A simple form for approximate determination of the heating value. ***It consists of*** a glass cylinder A, closed at the lower end to contain water, and a copper vessel B, called the condenser, which is closed at the upper end with a copper cover having a metal tube C, with a stop cock at the top. The lower end of B, is opened and is perforated near the open end by a series of small holes. D, is a metal base upon which B, is fixed by 3 springs attached to D, and pressing against the internal surface of B. A series of holes is made near the rim of D, to assist in mixing the water and allow of easier raising. Inside B, is a copper cylinder, E, called the furnace, which is closed at the lower end only and fits into a metal ring in the center of D. The weight of water used is 967 times that of the fuel burned, so that the rise in temperature of the water in degrees Fahrenheit is equal to the number of pounds of water which 1 pound of the fuel will, theoretically, evaporate from and at 212° Fahr. Ten per cent is added to this number as a correction for the heats absorbed by the apparatus itself.*

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*NOTE.—***In operation*** 30 grains of finely powdered fuel is mixed with 10 to 12 time its weight of a perfectly dry mixture of 3 parts chlorate of potash and 1 part niter. This fuel mixture is carefully pressed into the furnace E, and the end of a slow fuse about .5 inches long is inserted in a small hole made in the top of the mixture. The furnace is placed on the base D, the fuse lighted and the condenser B, with its stop cock shut is fixed over the furnace. Previously the cylinder A, has been charged with 29,010 grams of water, the temperature of which must be recorded. The condenser and base are now quickly placed in the cylinder and the fuse ignites the fuel mixture. The end of combustion will be shown by the ceasing of bubbles of gas rising through the water. The stop cock is opened so that water enters the condenser by the holes at the bottom and by moving condenser up and down, the water is thoroughly mixed so as to give it a uniform temperature. This is measured with a thermometer and recorded. By adding 10 per cent to the rise in degrees Fahrenheit of the temperature of the heating value of the coal is determined approximately. The heating value in *B.t.u.* is found by multiplying this by 970.4 (latent heat of steam at 14.7 pounds ab. pressure). The furnace works best with bituminous coal, but coke, anthracite and other more difficult combustibles can be tested by using a wider and shorter furnace and not pressing the fuel mixture down.

CHAPTER 59

FLUE GAS ANALYSIS

It has been said that fully one-fourth of the average plant's fuel supply is wasted. The reason why careful operation can lead to so much higher boiler efficiency is that this waste is largely in the heat carried away in the gases passing up the chimney, the excessive volume of which is usually not realized.

It is possible by means of a chemical analysis of the flue gases to determine the amount of fuel being wasted, which will serve as a guide to the fireman as to the efficiency of his firing methods. If the flue gas analysis show wasteful combustion, it indicates that some change must be made in one or more of the following items:

1. Method of firing for the coal in use (coking or spreading methods).
2. Condition of fuel surface as to being level to keep it free of air holes.
3. Depth of fuel.
4. Draught for the thickness of the fuel, and load.
5. Secondary air supply.
6. Condition of setting as to cracks.

Engineers are well acquainted with the term CO_2. Measurement CO_2 or carbon dioxide escaping through the chimney is a simple way of measuring the heat laden gases escaping up the chimney and is the index of combustion efficiency.

On acceptance tests, with careful firing, testing will show efficiency of 70% to 80%, but in practice with indifferent firing the same results are not obtained.

If the fuel were pure carbon and all of the oxygen combined with the carbon as it passed through the fuel bed, the resultant

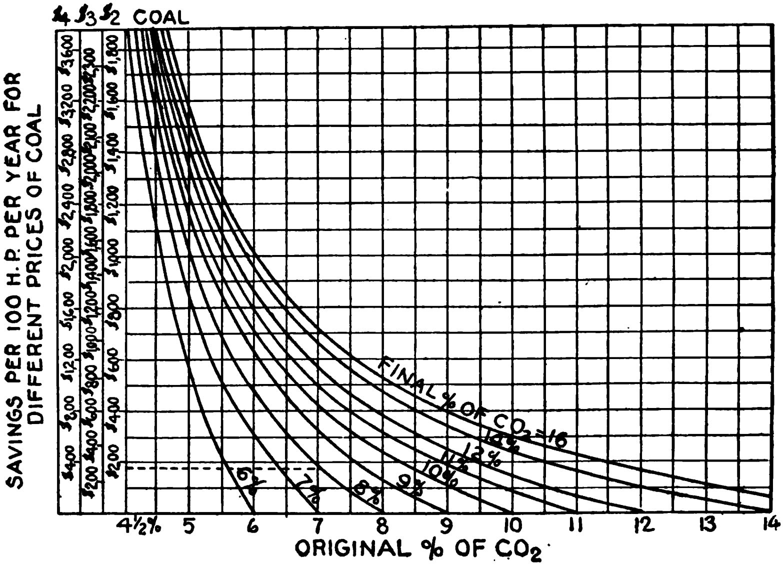

FIG. 3,441.—Saving in dollars per year per 100 boiler horse power by increasing the percentage of CO_2, in the flue gases. Suppose for instance, that the original percentage of CO_2 be 7, and with somewhat better firing it be increased to only 8 per cent. Starting at the 7 per cent mark on the horizontal base line and rising to the 8 per cent curve then running over horizontally to the left, as indicated by dotted line, gives with this measure of CO_2 and coal at $3.00, a yearly saving of $280.00.

products of combustion would be:

21% of CO_2
79% of nitrogen

In practice, however, it is found that excess air has to be introduced to insure complete combustion of ordinary coals and other fuels. This excess should be not less than 40% nor more than 60%. This lowers the percentage of CO_2 in practice to from 13 to 15%, depending upon the nature of the fuel.

All air which is introduced into the furnace in excess of 40% to 60% cools heated gases of combustion and is a detriment to furnace efficiency, for steam is made by virtue of the difference in temperature of the flue gases and the water in the boiler.

The following table gives the cooling effect due to excess air:

Cooling Effect of Various Percentages of Excess Air

(Based on coal containing C-85%; H-2.5%; N-1%; Ash-7.75%, and *B.t.u.*-14,750 per pound Temperature of external air-0° F.)

Excess Air in Per Cent.	Ideal Temperature of Combustion. Degrees	Loss of Temperature Due to Dilution Degrees	Temperature of combustion compared with that developed by Minimum Quantity of Air	Boiler capacity in per cent. of capacity at 40% excess air Flue gas temperature assumed constant at 600°. Boiler temperature assumed as 360°F.
O (or Min. Quantity)	5,132° F			
10% excess	4,710	422	91.8%	....
20	4,352	780	84.8	....
30	4,044	1,088	78.8	....
40	3,777	1,355	73.6	100
50	3,543	1,589	69.0	93.5
60	3,336	1,796	65.0	88.2
70	3,153	1,979	61.4	83.0
80	2,988	2,144	58.2	78.5
90	2,840	2,292	55.3	74.5
100	2,705	2,427	52.7	70
125	2,419	2,713	47.1	63.0
150	2,188	2,944	42.6	56.6
175	1,997	3,135	38.9	51.5
200	1,837	3,295	35.8	47.0

Excess air also tends to chill the flue gases. If carried to such an extent that the gases are chilled below the ignition point, carbon (soot) is deposited on the metal surfaces of the boiler and the chimney smokes. Carbon which might otherwise have been burned and added to the heat value of the gases is lost. It also becomes a detriment by preventing the absorption of heat by the boiler surfaces.

A little increase in the percentage of CO_2, obtained in better firing methods will represent a considerable decrease in excess air carrying heat away up the chimney.

The curves, fig. 3,441 show, as an example, the dollars saved per 100 boiler horse power operating continuously for one year, for various prices of coal and various increases in CO_2.

The principal constituents of the gases in the flue or chimney are:

1. Oxygen
2. Nitrogen
3. Carbonic dioxide
4. Carbonic nonoxide

The object of the analysis is to determine the percentage of these gases present, and to deduce therefrom the amount of air actually entering the furnace, as compared with the air theoretically necessary for combustion. If all the air admitted to the furnace could be brought into such intimate contact with the fuel that every atom of the oxygen contained in it could be utilized for the purposes of combustion, the escaping gases would practically consist of only carbonic acid and nitrogen—that is, each atom of the carbon of the fuel would unite with two atoms of oxygen in the air admitted, forming CO_2, the nitrogen passing through unchanged.

Such a result is, however, unattainable, and unless an excess of air be admitted, the carbon will not be completely consumed, and CO, consisting of one atom of carbon combined with one atom of oxygen, will be formed, instead of CO_2.

The formation of CO results in a very serious loss of heat, and must therefore be prevented by admitting some excess of air.

The excess of oxygen required is generally from 6% to 8% of the volume of the gases. If there be less than 6% of oxygen there will almost certainly be traces of CO.

There are upon the market a number of instruments for analyzing flue gases which are not difficult to operate and give results sufficiently accurate for practical purposes.

Sampling Gases.—Preliminary to making an analysis a sample of the flue gases must be obtained and in order for the analysis to be of any value it is necessary that the sample taken represent correctly the *average* of the flue gases.

There are numerous methods of obtaining an average sample and considerable difference of opinion exists as to which is the best.

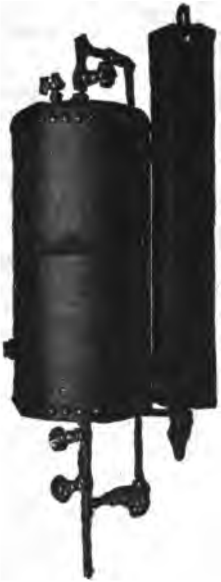

FIG 3,442.—Precision gas collector. *It consists of* a sub-standard galvanized iron tank with piping arranged for constantly drawing a sample of gas from the flue. There is a permanent oil surface for the water in the collector to prevent the absorption of CO_2 by the water.

Am. Soc. of M. E. Method.—The sample for flue gas analysis should be drawn from the region near the center of the main body of escaping gases using a sampling pipe not larger than ¼ inch gas pipe. The point selected should be one where there is no chance for air leakage into the flue which could affect the average quality.

In a round or square flue having an area of not more than ⅛ of the grate surface, the sampling pipe may be introduced horizontally at the center line, or preferably a little higher than this line, and the pipe should contain perforations extending the whole length of the part immersed, pointing toward the current of gas, the collective area of the perforations being less than the area of the pipe. The pipe should be frequently removed and cleaned.

It is advisable to take samples both from the flue and from the furnace, so as to determine the amount of air leakage through the setting and the changes in the composition of the gas between the furnace and the flue.

Bureau of Mines Method. —A water cooled tube or a quartz tube is preferred to a plain metal tube.

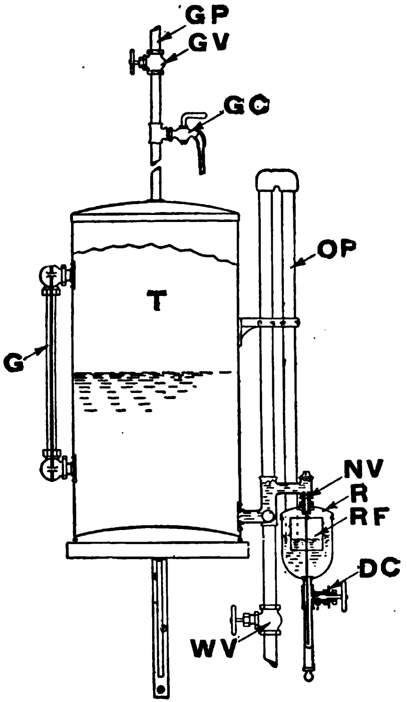

FIG. 3,443.—Hays automatic gas collector. ***In operation,*** close valve GV, open gas cock GC, and turn on the water by opening valve WV. Should the water overflow through the overflow pipe OP, before the tank is full, remove plug of gas cock GC, and see that opening is not stopped with grease or dirt. If there be no stoppage, close valve WV, gradually until overflow ceases. When the tank has been filled water will overflow through pipe OP. ***To collect a sample,*** first close WV and GC, then open GV. Water will then flow from the Tank T, into flow regulator R, and be discharged through drip DC, the drip cock DC, should be set to just about fill the tank with gas during the sampling period. Analysis should be made at each end of each watch. In operating the collector it is necessary to use the valve WV, GV and cock GC. The sample may be taken from the collector and the tank T, refilled with water without disturbing DC. ***To pump gas from the collector*** set cock of the analyzer in the open position; hang leveling bottle upon the flange of the case and be sure it is filled with water. Close GV, open GC, and WV. Water will flow into the back and force gas out into the analyzer.

NOTE.—*Hays* objects to the ordinary perforated sampling pipe because: 1, gas will flow fastest along the lines of least resistance; 2, the nearest hole will furnish more gas than the next one, etc.; 3, liability of some of the small holes to become stopped up; 4, no means of knowing when holes are stopped up; 5, the velocity of the gas decreases from the center of the boiler toward the sides, so that even if it were possible to secure uniformity of gas flow through

Ques. What determines the location of the sampling tube?

Ans. The use to be made of the gas analysis.

If the total heat losses be the desired data, the sample should include all the air leakage into the setting; if the analysis be made as a guide for controlling the fire, the gas sample should be taken at some point before they are diluted by leakage through the setting.

Ques. What method of taking the sample is most desirable?

Ans. It is best to draw a *continuous* sample, using a suitable ejector, and provide a branch pipe from which to obtain the test sample.

The test sample can then be taken either momentarily or continuously according to requirements. Momentary samples should be taken every five minutes.

The conditions at the time of taking the sample should be recorded in order to be able to determine the meaning of the analysis.

Speed is essential in taking gas samples as conditions may change from instant to instant.

Flue Gas Collectors.—These are used for holding an average sample over a given time, obtained by collecting samples every few minutes. These holders should be of sufficient capacity to hold 150 to 200 cubic centimeters of gas and may be of the form shown in fig. 3,443.

The practice of collecting gas over water in collectors is objectionable in that the water may absorb or give up CO_2 thus

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NOTE.—*Continued.*
all of the perforations in the tube, the sample derived would not be an average one; there is no value of taking a cross sectional sample from side to side unless there be added to this another cross sectional sample extending longitudinally from baffle to baffle.

rendering the percentage of CO_2 incorrect in the gas sample. A brine solution will absorb CO_2 less readily than will water.

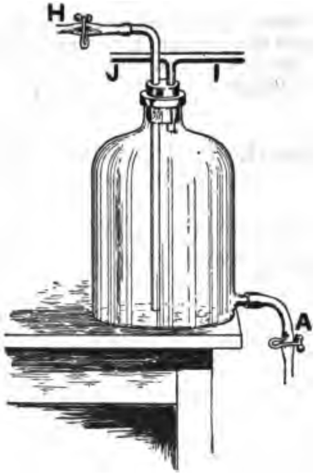


FIG. 3,444.—Flue gas collector, capacity 150 to 200 *c.c.* of gas. The bottle is provided with a cork through which are passed two tubes, one of which connects through the rubber tube H, to the water supply, and extends to the bottom of the bottle, the other extends only through the cork and is provided with a T connection, one branch of which is connected by means of glass and rubber tubing to the sampling tube, while the other connects to the suction side of the ejector used to draw the gas. From the bottom of the bottle is a glass tube with a rubber connection which connects the water to water. ***In operation,*** pinch cock A, is closed and H, opened thus allowing the water to fill the bottle completely. The pinch cock H, is then closed and J, opened, and the gas drawn through. The T, by the gas pump in order to remove all air which may remain in the gas connections. After this has been running for some time the pinch cock A, is opened thus allowing the water in the bottle to drain out and draw in the flue gas through the tube J, when A, is again closed. ***To discharge the gas*** into the testing apparatus, connect tube to the gas instrument and close pinch cock in J; by opening pinch cock H, water flows to the bottom of the bottle and forces the gas into the instrument.

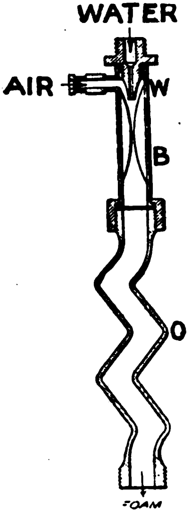
Gas Pumps.—There are three forms of pumps in general use for drawing the gas into the sampling apparatus:

1. Jet pumps.
2. Fall pumps.
3. Steam pumps.

An example of the first mentioned type is shown in fig. 3,445, which consists of a water jet, resembling very much the common boiler injector with an air or gas connection and a restricted portion B, with a zigzag tube C, which is used for breaking up the water into foam.

Ques. What is the principle of a fall pump?

Ans. Its operation depends upon the weight of the water to maintain a vacuum.



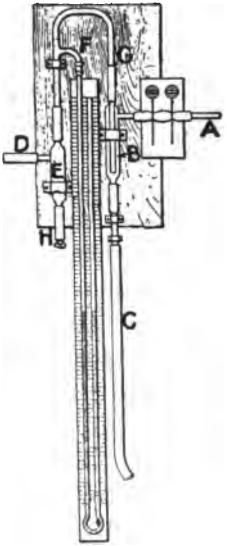


Fig. 3,445.—Richards jet pump. ***In operation,*** water entering at the top draws the air or gas through the side connection by forming successive pistons through the restricted passage.

Fig. 3,446.—Bunsen fall pump. ***It consists of*** a water connection attached to an enlarged tube B, and discharges the water through the tube C, which, in order to maintain a perfect vacuum, should be 34 feet high. In the enlarged tube B, is inserted a smaller glass tube which extends nearly to the bottom and connects at the other end through G, E and D, to the gas or air connection. The enlarged portion E, is provided to catch any water which may be drawn back into the gas connection, and the stop cock H, is used to drain it off. A scale and mercury U tube is provided in order to ascertain the exact vacuum maintained in the gas tubes to which it is connected through the tube F. ***In operation,*** when it is desired to draw a sample of the gas, the tube D, is connected to a branch of the rubber tubing I, shown on the sampling apparatus. The water connection is made through the tube A, and by the continual falling of the water acting as a series of pistons through B, and C, gas is drawn from the flue.

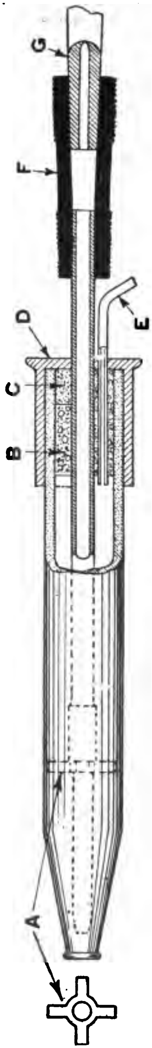


Fig. 3,447.—Steam pump. *In operation*, the steam connection, which is made through the pipe G, is turned on and draws air or gas through the connection E.

Ques. Describe a steam pump.

Ans. As shown in fig. 3,447, a steam pump consists of a large tube contracted at one end into which is inserted a cork B, and cement C, fitted with a covering D, provided with a steam tube G, and an air tube E, the steam tube extending nearly to the end of the large tubing and held in place by the washer A.

Gas Analysis.—Carbon dioxide gas is absorbed by caustic potash. This forms the basis of operation of all carbon dioxide instruments. The usual process of measuring the carbon dioxide in flue gases is that used by Orsat which form the principle of most automatic CO_2 recorders.

Ques. Describe briefly the usual process of gas analysis?

Ans. A sample of the flue gas is taken and its volume measured. The gas is then passed through or brought into intimate contact with a solution of caustic potash. As CO_2 is measured by volumetric displacement, liquid caustic is used. After the CO_2 contents have been absorbed, the volume of the gas is again measured. The difference between this and the original volume gives the amount of CO_2 in the gas and divided by the original volume, gives the percentage of CO_2.

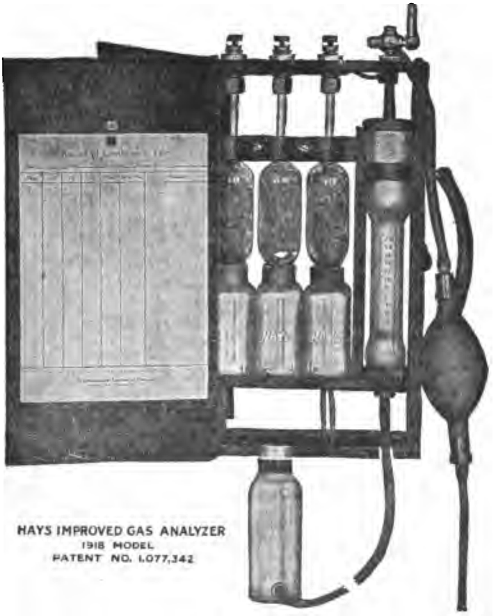
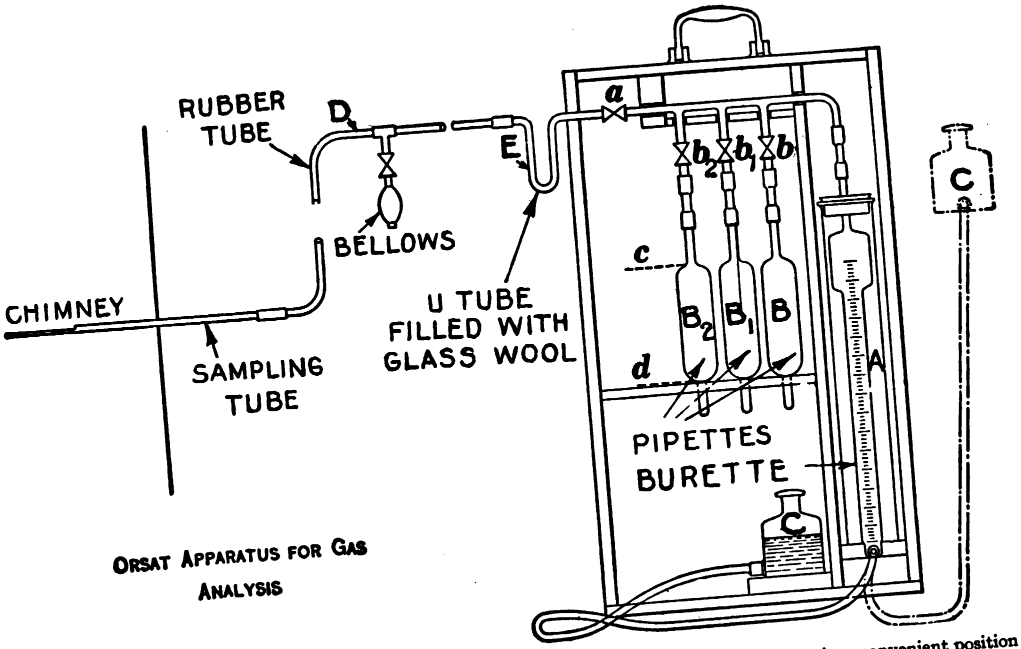


Fig. 3,448.—Hays gas analyzer. Size, 3×7¼×12¾; weight charged, 7½ pounds.

NOTE.—***Care of Orsat Apparatus.*** The operator will save time and expense and prevent many troublesome difficulties by taking good care of the Orsat apparatus. If the ground glass surfaces of stop cocks be allowed to stand without cleaning, they will become cemented together by alkaline solutions, and the cocks cannot be operated. The only remedy is to keep the stop cocks free from alkali and lubricated with a thin film of vaseline. If too much vaseline be used, the openings in the cocks and capillary tubes become stopped with the excess. A properly lubricated stop cock has the appearance of a single piece of thick glass. If a solution be accidentally drawn into a stop cock, the cock should be removed at once and the surfaces wiped clean with a cloth or piece of soft paper, and lubricated with a thin film of vaseline. If necessary the header should also be removed and washed free from alkali. The water in the burette and leveling bottle should be saturated with flue gas and should be changed as often as it becomes dirty. If the water become alkaline by solution being drawn into the header and washed into the burette, it should be changed at once. If this be not done carbon dioxide will be absorbed by the alkaline water and the percentage of CO_2 indicated by the analysis will be low. The joints made with rubber tubing should be examined and the apparatus tested for leaks before work is started. This is especially necessary when the Orsat apparatus is not used frequently.



Orsat Apparatus for Gas Analysis

FIG. 3,449.—Three pipette Orsat apparatus for gas analysis and connections. Place the apparatus in a convenient position near the chimney and connect up as shown, the bottom of the apparatus being, say, about 3 feet above the level of the feet of the observer; connect the end of the sampling tube to the apparatus by a rubber tube D, having a U tube filled with glass wool inserted between the apparatus and the boiler, so as to intercept dust. The bottle C, is filled about two-thirds full of water, and connected to the bottom of the measuring tube A, by a rubber tube. When this bottle is placed on the top of the case containing the apparatus, the water will flow into the vessel A. If now the bottle C, be placed below the apparatus and the cock a, it is evident that, as the water flows out of A, the gas will be drawn in from the flue and take its place. Draw in the

Fig. 3,449—*Text continued.*

gas well below the zero mark, and cut off the connection with the flue by closing cock *a*, then lift bottle C, so that the water level in it coincides with the zero mark in the measuring tube, and open the three-way cock *a*, to the atmosphere allowing the surplus gas to escape, thus obtaining tube A, full of gas at atmospheric pressure. Again close the cock *a*. Then, by opening one of the cocks, *b*, *b*1, or *b*2, the gas contained in the measuring tube A, can be forced into either of the vessels B, B1, or B2, by raising the bottle C, so that the water flows into A, due care being taken that the water never rises above the mark at the top of the measuring tube. The absorbing vessels B, B1, and B2, should be filled with the reagents, rather more than half-way up. *It is essential that the gases to be tested be passed through the different reagents in the order given above, otherwise incorrect results will be obtained.* The vessels B, B1, and B2, contain small glass tubes. These are used with the object of giving a greater wetted surface to absorb the gas introduced. The tubes with copper wire around them are for the vessel B2, containing cuprous chloride. The measuring tube A, is, for convenience of calculation, marked off into 100 parts, so that percentages may be read off easily. At the moment of measuring the volume of gas in the graduated tube, the water bottle must be held at such a height that the level of the water in it is exactly the same as in the graduated tube, otherwise the gas will be compressed or expanded by the difference between the two columns of water. Before commencing the test get rid of as much as possible of the air in the tubes by using the small hand bellows shown in figure; then draw several samples of the gas into the measuring tube, and discharge each in its turn to the atmosphere through the three-way cock *a*. Having obtained an undiluted sample, shut the cock *a*, open the cock *b*, and force the gas into the vessel B. Draw the gas back into the vessel A, and repeat the operation, three or four times, so as to ensure the thorough absorption of the CO_2. The last two readings should give the same result, showing that the absorption is complete. Follow the same procedure with the remaining two vessels B1, and B2, taking the reading of the reduced quantity of gas in the vessel A, after each operation. CO_2 is absorbed by the caustic potash solution very quickly, and it will be found that passing the gas three times through the absorbing vessel B, will generally be quite sufficient. The gas, however, must be passed through the pyrogallic solution at least five or six times, in order that the oxygen may be all absorbed. If this be not done, the oxygen remaining will be absorbed by the cuprous chloride, and will be mistaken for CO, although there may be none of that gas present. The total of the percentages of the three gases CO_2, CO, and O, should be about 19.5, and this rule may be used as a rough check on the analysis.

NOTE.—In Fig. 3,449, the vessels B, B1, and B2, contain the following reagents:

Vessel	Reagent	To absorb
B	One part commercial caustic potash and two parts of water (solution of Sp. Gr. 1.2)	CO_2
B1	Five grammes pyrogallic acid dissolved in 15 *c.c.* water, 120 grammes caustic potash dissolved in 80 *c.c.* water. The two solutions to be mixed	O
B2	Saturated solution cuprous chloride in hydrochloric acid	CO

Care should be taken to keep the pyrogallic solution from air, as it absorbs oxygen rapidly. It is best to mix the potash solution with it in the tube.

NOTE.—According to Terman, the absorption capacities of Orsat solutions are as follows: *Potassium hydroxide,* 40 times its own volume before it becomes too weak; *potassium pyrogallate,* twice its own volume; *cuprous chloride.* its own volume of Co. Some authorities give higher values, but this solution is cheap, and it is not good at the best.

Ques. Describe the Orsat apparatus for analyzing flue gases?

Ans. It is a portable instrument contained in a wooden case with removable sliding doors front and back, and consists essentially of a measuring tube or burette, three absorbing bottles or pipettes, and a leveling bottle, together with the

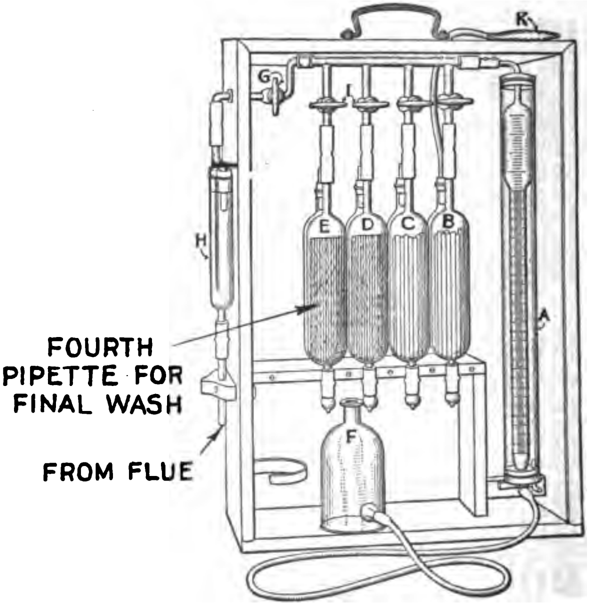


FIG. 3,450.—Four pipette Orsat apparatus for accurate analysis. The first pipette B, contains a solution of caustic potash the second C, an alkaline solution of pyrogallic acid and the remaining two D, and E, a solution of cuprous chloride. Each pipette contains a number of glass tubes, to which some of the solution clings, thus facilitating the absorption of the gas. In the pipettes D, and E, copper wire is placed in these tubes to re-energize the solution as it becomes weakened. The rear half of each pipette is fitted with a rubber bag, one of which is shown at K, to protect the solution from the action of the air. The solution in each pipette should be drawn up to the mark on the capillary tube. The various operations are performed the same as with the three pipette apparatus with the exception that after the gas has been in pipette D, it is given a final wash in E, and then passed into the pipette C, to neutralize any hydrochloric acid fumes which may have been given off by the cuprous chloride solution, which, especially if it be old, may give off such fumes, thus increasing the volume of the gases and making the reading on the burette less than the true amount.

connecting tubes and apparatus. The bottle and measuring tube contain pure water; the first pipette, sodium potassium hydrate dissolved in three times its weight of water; the second, pyrogallic acid dissolved in a like sodium hydrate solution in the proportion of 5 grams of the acid to 100 cubic centimeters of the hydrate; and the third cuprous chloride.

Ques. Briefly, how does it work?

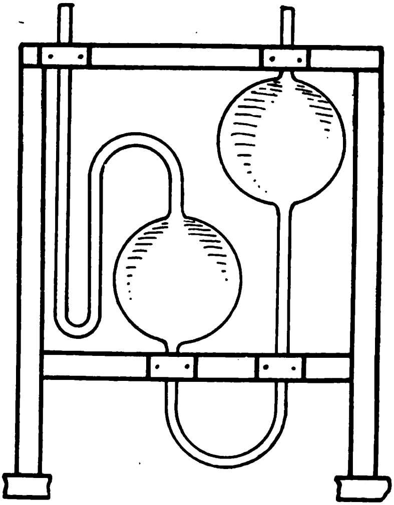


FIG. 3,451.—Hempel pipette. It works on the same principle as the simple form of Orsat apparatus, excepting that the absorption may be hastened by shaking the pipettes bodily bringing the chemical into more intimate contact with the gas. The illustration shows a single pipette set; several of these are necessary for the treatment of the different constituent gases. For each process, after absorption the quantity absorbed is determined by returning the gas into the measuring burette and observing the successive differences.

Ans. After completely drawing out the air contained in the supply pipe, a sample of the gas is drawn into the measuring tube by opening the necessary connections and allowing the water to empty itself from the tube and flow into the bottle. The quantity of gas drawn in is adjusted to 100 cubic centimeters.

By opening one by one the connections to the pipettes and raising and lowering the water bottle, the sample is alternately admitted to and withdrawn from the pipettes, and the ingredients one by one absorbed.

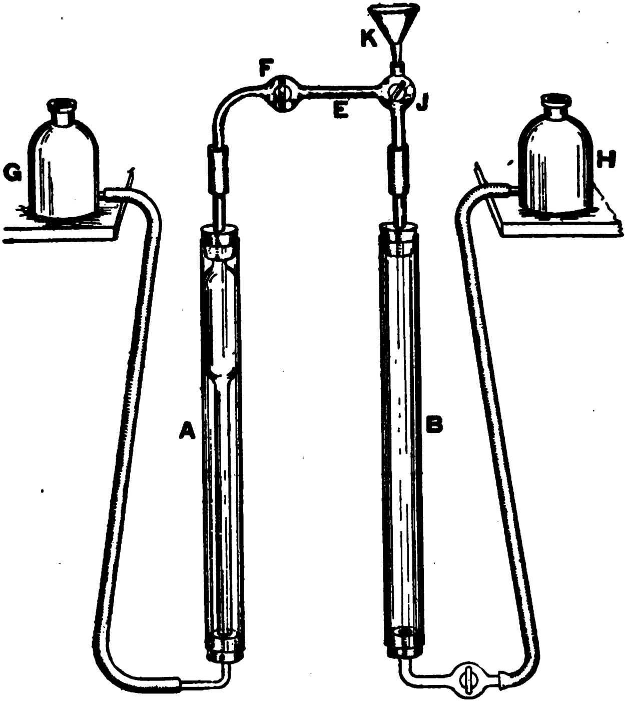


FIG. 3,452.—Eliot apparatus. ***It consists of*** a measuring tube A, a heating tube B, with a top connection E, provided with a stop cock F, and a three-way cock J. Pressure bottles G, and H, are provided with rubber connections to the tubes A, and B, as shown. ***In operation,*** distilled water is put into the tubes and bottles, and the bottles are placed upon the shelves provided for them, the stop cocks F, and J, being closed. Connection is made to the gas holder through J, which is turned to open straight from the tube B. By lowering the bottle, H, the gas is then drawn into the treating tube when J, is turned to connect B, and E. By opening F, raising H, and lowering G, the gas is drawn into the measuring tube, A, the water in G, being kept at the same level as in A, by raising or lowering the bottle, H. The tube, A, is graduated so that the amount of gas it contains can readily be determined from the scale, and this amount for convenience is usually 100 cubic centimeters. The stop cock F, is then closed and with J, opened, the bottle H, is raised until all gas is expelled from the tube B. By turning J, E, is connected to B, F, is then opened and the

The first pipette absorbs carbon dioxide CO_2, the second, oxygen O, and the third, carbon monoxide CO. The quantity absorbed in each case is determined by finally returning the sample to the measuring burette and reading the volume.

The percentage of CO_2 is read directly by the first absorption. Those of the other two ingredients are the respective differences between the readings taken after successive absorptions.

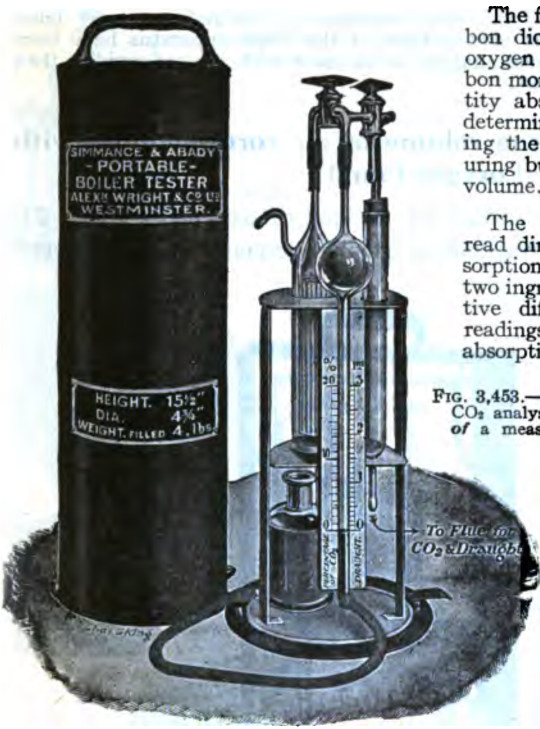


FIG. 3,453.—**Precision "boiler tester" or CO_2 analysis apparatus.** ***It consists of*** **a measuring burette and a concentric glass absorption pipette filled with five glass tubes, mounted on a circular metal stand with stop cock, and bottle containing water. The gas passes through a filter to neutralize the soot before entering the burette. The burette is of such form as to be adapted for use as a draught gauge and also as a measuring burette for the percentage of CO_2 having draught and CO_2 scales. On being connected to the flue with the water leveled to the zero of the scale by the bottle, the draught is shown on the scale when the cock is opened. Without disconnecting, the bottle is used to draw in a sample of gas, which is then analyzed and the percentage of CO_2 is read off the other side of scale.**

FIG. 3,452.—***Text continued.***

gas passed into B, for treatment. A 5 per cent. solution of caustic potash is then poured into the funnel, K, and allowed to drip along the sides of the treating tube until no further absorption takes place. The gas is then passed into A, and measured, its loss in volume, which was carbon dioxide, being noted. Treatment for oxygen is then proceeded with, using, instead of the caustic potash, a solution of 5 grams of pyrogallic acid in 15 cubic centimeters of distilled water, added to 120 grams of caustic potash in 80 cubic centimeters of water, which is dropped from funnel into B, measuring the gas and noting the loss of volume due to absorbing the oxygen. Carbon monoxide is then absorbed by a solution made from 10.3 grams of copper oxide in 100 cubic centimeters of concentrated hydrochloric acid. In each case the amount of gas originally drawn being 100 cubic centimeters, the decrease in volume represents the percentage of the gas which has been absorbed by the treating solution. The chemicals must be used in the order indicated or the results will not be correct. Care must be taken when passing back and forth and when letting in chemicals that no gas escapes and no air enters the apparatus.

The manipulation of the Orsat apparatus is explained in greater detail in fig. 3449. Various modifications of the Orsat apparatus have been developed which enables analysis to be made with greater rapidity than the form just described.

Ques. How is the volume of air corresponding with any given volume of oxygen found?

Ans. As the percentage by volume of oxygen in air is 21. the volume of air corresponding with any given volume of oxygen may be found by multiplying by $\frac{100}{21}$, or 4.762. The volume of air corresponding to a given volume of CO_2, may also be found by multiplying by the same figures.

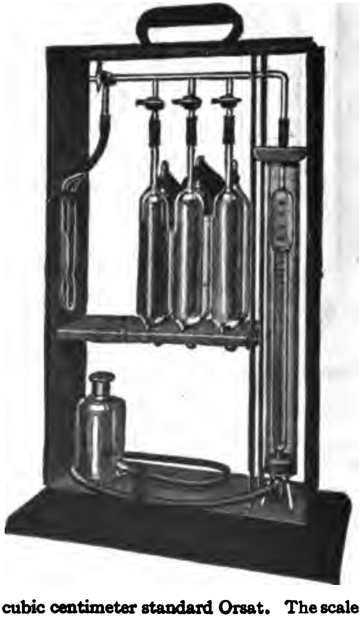


Fig. 3,454.—Precision 100 cubic centimeter standard Orsat. The scale divisions on the burette are divided into tenths.

	CO_2	O
Example.—Analysis shows............	13.5%	6%

Then air used for combustion = 13.5×4.762 = 64.3
And excess air = 6×4.762 = 28.6

92.9

The percentage of excess air above that which is necessary for combustion is therefore:

$$\frac{100\times28.6}{64.3}=44.5\%$$

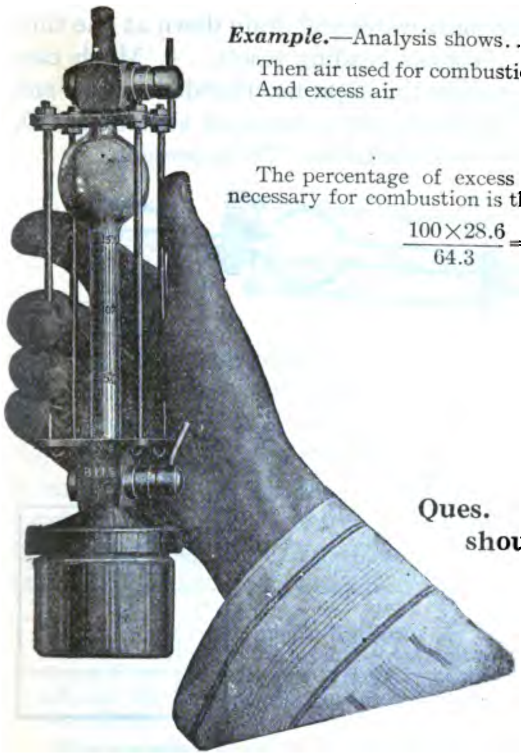
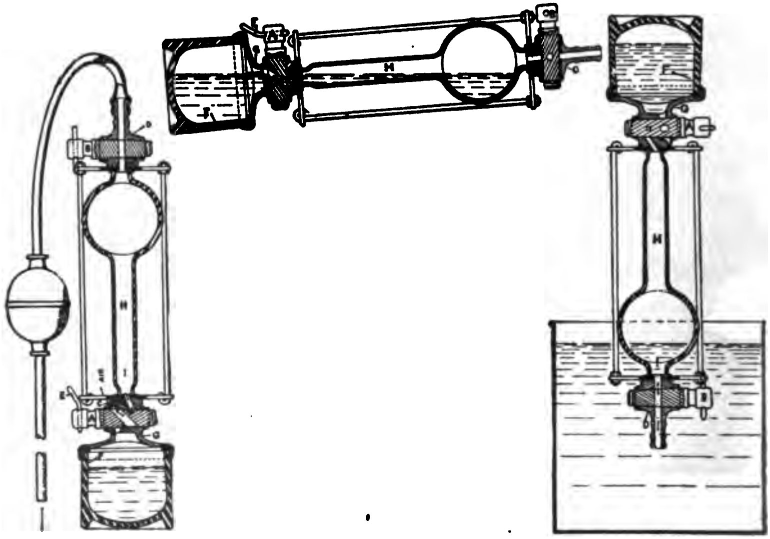


FIG. 3,455.—Bacharach pocket CO_2 indicator.

Ques. **What precautions should be observed in making a gas analysis with the Orsat apparatus (fig. 3,449)?**

Ans. 1. The absorbent should not be forced below the point ***d,*** or some of the gas may escape and be lost, and, of course, an incorrect result obtained. 2. The absorbent must be at exactly the same level in the tube—say at ***c,*** when measuring the volume after the gas has been absorbed as before. 3. Time must be allowed for the water to drain down the sides of the tube before taking a reading. The time must be the same on each occasion, otherwise more water will drain down at one time than another, and an incorrect reading result. 4. Much care should be taken in preparing the cuprous chloride solution and it must be known to be fresh and capable of absorbing CO, otherwise no CO will be indicated when CO is present.



Figs. 3,456 to 3,458.—Manipulation of Bacharach pocket CO$_2$ indicator. After taking the indicator out of the case, the rubber stopper is removed and the two cocks A and B, are put into their places. The cocks are easily distinguished from each other, cock A, having a bent handle. The glass jar F, at the lower end is then removed from the metal body G, and filled with the absorbing solution, after which it is screwed on again. With the pump attached to the open upper valve D, and the cock A, of the lower valve turned, so that the glass measuring tube H, in center is open to atmosphere through hole C, the indicator is ready for use. The glass jar F, having once been filled with KOH (one filling is enough for 200 determinations), the open end of the pump is connected to the gas line from which a sample is to be taken. The gas is now pumped in, at the same time allowing the air to escape to the atmosphere through hole C. When a fair sample of gas has been collected (about 30 strokes of the pump being sufficient) the upper cock B, is closed. The lower cock A, is then turned 180° to permit the gas and KOH to come in contract for chemical action, helping the process by holding it inclined downward and shaking it. When the solution has been drained back to the glass jar F, the lower cock A, is closed and the indicator held vertically upside down and immersed in water. The submerged cock B, is opened and the ingoing water, which takes the place of the absorbed CO$_2$ is leveled with that outside. The cock B, is then closed and the indicator brought to its base. Opening the cock B, the per cent. of CO$_2$ is read off on the tube at the water level. Turning the apparatus upside down, the water will run out through the open cock B, and the instrument is ready for another determination.

CHAPTER 60

CO_2 RECORDERS

What CO_2 Indicates.—The CO_2 indication answers most practical purposes. If greater certainty or refinement be desired after the CO_2 has been brought up to the required percentage, the CO determination must be made. While high CO_2 indicates a small amount of excess air, it does not necessarily mean a correspondingly good combustion. 1% of CO in the flue gas would be a negligible indication of the quantity of excess air, but might mean 4½% loss due to incomplete combustion.

Low CO_2 may be caused by excess air, insufficient air (high CO), or improper mixture of the air and gases, but a surplus of air is the cause in almost every instance. The difference between the CO_2 percentage in the last and the first passes indicates the air leakage in the setting. CO_2 is also affected by the character of the fuel.

The more hydrogen in the fuel, the less CO_2 in the flue gases. If the fuel were all carbon, there would be 21% CO_2; if all hydrogen, no CO_2 in the gases.

Unreliability of CO_2 Readings Taken Alone.—It is generally assumed that high CO_2 readings indicate good combustion and hence high efficiency. This is true only in the sense that such high readings do indicate the small amount of excess air that usually accompanies good combustion, and for this reason high CO_2 readings alone are not considered entirely reliable.

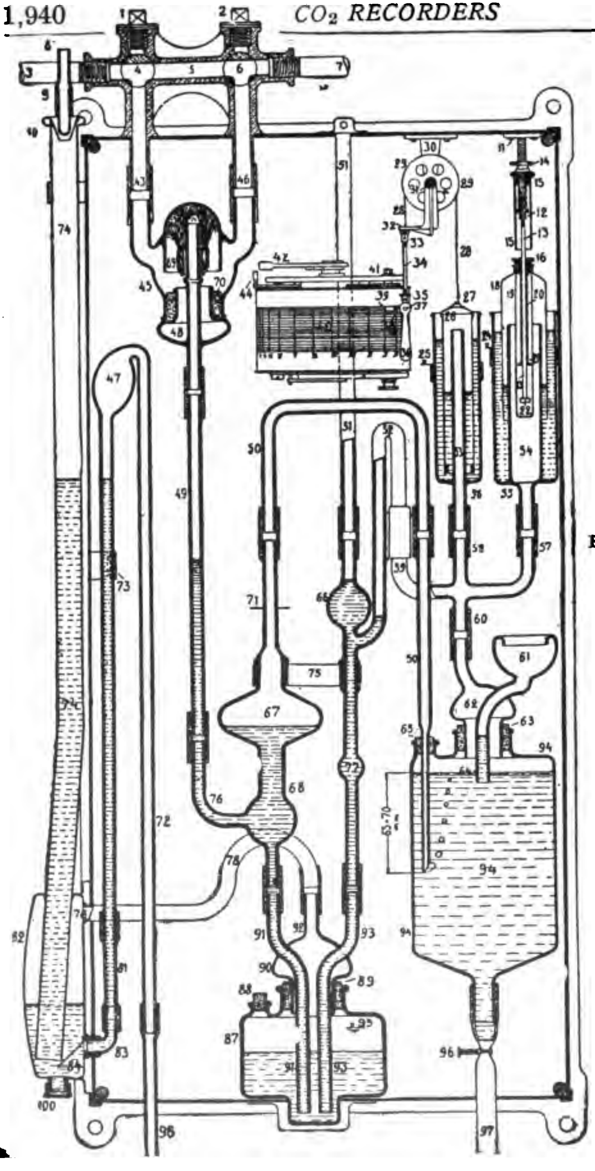


Fig. 3,459.—Sarco type C, CO_2 recorder. For description and explanation of operation see page 1,941.

Ques. Whenever a CO_2 recorder is used what should be done from time to time?

Ans. Since a CO_2 recorder does not give CO readings, it should be frequently checked with an Orsat or Hempel apparatus to determine if CO be present.

As the percentage of CO_2 in flue gases increases, there is a tendency toward the presence of CO, which, of course, cannot be shown by a CO_2 recorder, and which is often difficult to detect with an Orsat apparatus.* It is not safe, therefore, to assume without question from a high CO_2

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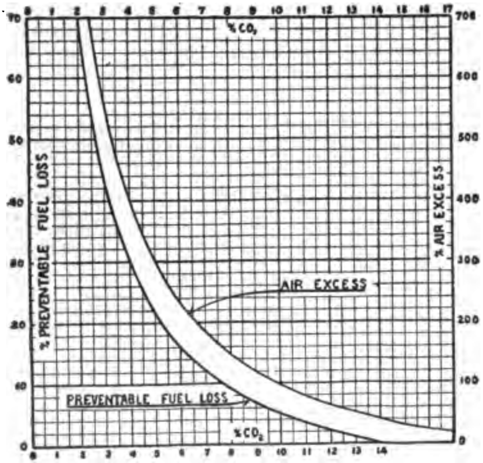
*NOTE.—As before mentioned, the greatest care should be taken in preparing the cuprous chloride solution in making analyses and it must be known to be fresh and capable of absorbing CO.

FIG. 3,459.—Sarco type C, CO_2, recorder. Motive power is a fine stream of water with two foot head. *In operation,* the water now flows through tube 74 into the power vessel 82: here it compresses the air above the water level, and this pressure is transmitted to vessel 87 through tube 78. The pressure thus brought to bear on the surface of the liquid with which vessel 87 is filled (to mark 95), sends this upwards through tubes 91 and 93. Thence it passes up into vessels 68, 67, 77 and 66, and into tubes 49, 51 and 52. It rises until it reaches the zero mark 71, which will be found on the narrow neck of vessel 67. At the moment it reaches this mark the power water, which, simultaneously with rising in vessel 74, has also travelled upwards in syphon 72, will have reached the top of this syphon, which then commences to operate. Through this syphon 72 a much larger quantity of water is disposed of than flows in through injector 9, so that the power vessels 74 and 82 are rapidly emptied again. The moment the pressure on vessel 87 is thus released, the liquids return from their respective tubes into this vessel. Assuming tube 49 to be in connection with a supply of flue gas, a sample of this is drawn in from the continuous stream which passes through 43, 45 and 46, as the liquid recedes in 49, by the partial vacuum which is created by the falling of the fluid. As soon as the liquid has dropped below point 76, which is the inlet of the flue gas into vessel 67, the gas rushes up into this vessel. As soon as the flow in the syphon stops, vessel 82 begins to fill again, and the liquids in tubes 91 and 93 rise afresh. The gas in 67 and 68 is now forced up into tube 50, and caused to bubble right through a solution of caustic potash (*spec. grav.* 1.27) with which vessel 94 is filled (to point 64 marked on the outside). In this process any carbon dioxide (CO_2) that may be contained in the gas is quickly absorbed by the potash. As the gas has to pass through the potash, the absorption is rapid and complete. The remaining portion of the sample collects in 62, and passes up through 60 into tubes 57 and 58. (It cannot pass out at 59, as this outlet is sealed by the liquid in 52.) The gas now passes under the two floats 18 and 26, whereof the former is constructed larger and lighter and will, therefore, be raised first. By turning the thumb screws 14 and 15, the stroke of this float is adjusted until just 20 per cent of the whole of the sample remains to raise float 26, when nothing is absorbed in 94, as would be the case if air be passed through the Recorder. This float has attached to it pen 36, which is caused to travel downwards on the chart, when 26 rises. If no CO_2 were contained in the gas, nothing would be absorbed by the potash in 94, and the whole of the 20 per cent reach float 26. Thus the pen would be caused to travel the whole depth of the chart from the 20 per cent line at the top to the zero line at the bottom. Any CO_2 gas contained in the sample would be absorbed by the potash, a correspondingly less quantity would reach float 26, and pen 36 would not travel right down to the bottom of the chart, *i.e.*, the zero line. Thus any CO_2 absorbed will be indicated by a shorter travel of the pen—the actual percentage being given by the line on which the pen stops. (See fig. 3,460.) On the return stroke of the liquid, the gas is pushed out from under floats 18 and 26, through tubes 75 and 58, and into tubes 59 and 52. From here it passes out into 66 (as soon as the liquid has fallen below the outlet of tube 52), and through tube 51.

reading that the combustion is correspondingly good, and the question of excess air alone should be distinguished from that of good combustion.

The effect of a small quantity of CO, say one per cent, present in the flue gases will have a negligible influence on the quantity of excess air, but the presence of such an amount would mean a loss due to the incomplete combustion of the carbon in the fuel of possibly 4.5 per cent of the total heat in the fuel burned. When this is considered, the importance of a complete flue gas analysis is apparent.



Flue Gas Analyzers vs. CO_2 Recorders.—In most boiler plants great quantities of fuel are wasted, the chief loss being due to excess air. To determine the loss due to excess air, hand operated flue gas analyzers and CO_2 recorders are employed.

FIG. 3,460.—Bacharach curves for coal fired furnaces, showing that about 40% of excess a. is necessary to obtain the most efficient combustion. This is indicated by the highest CO_2 contents obtained by the amount of air as shown by the two curves. A greater percentage of excess air reduces the CO_2 contents and therefore increases the fuel loss. Thus, for 300% excess air, the CO_2 drops to 5% while the corresponding fuel loss becomes 21%.

The first ordinarily is an Orsat or one of its modifications; the second, one of the several different types of recording instruments on the market.

A hand gas analyzer is a useful device, and every boiler plant, no matter how small, should have one for testing purposes. The instrument is simple, but as its operation requires considerable time and the information obtained is not immediately visible to the fireman, its value is reduced.

An automatic recorder shows from 10 to 20 times every hour what quantity of CO_2 is in the flue gas, and it operates continuously, thus enabling the chief engineer to know how careful or careless his firemen were during the night.

How a CO_2 Recorder Works.—The principle upon which most recorders work is based upon *the absorption of* ***CO_2*** *from flue gases by a solution of* **caustic potash.**

There are four essential operations to be performed by a recorder for each CO_2 determination.

1. Measuring out a definite quantity of flue gases.

2. Passing the measured sample through the caustic potash solution which absorbs the CO_2, decreasing the volume of the gases in proportion, and recording the decreased volume after absorption of the CO_2 by the caustic potash solution.

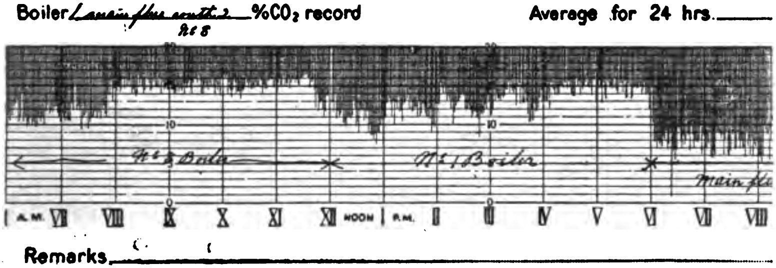
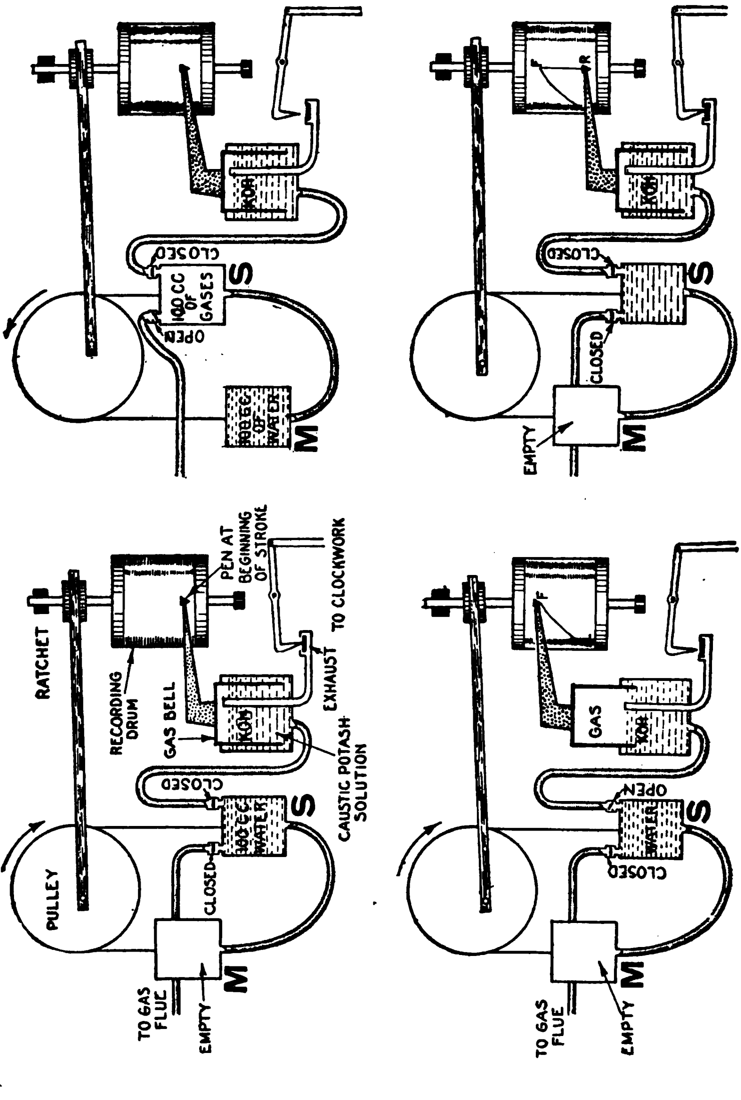


FIG. 3,461.—Sarco type C, CO_2 recorder chart. This section of a 24-hour chart shows successively the recorded CO_2, in two separate furnaces giving the main flue.

3. Exhausting the recorded sample, thus bringing the apparatus back to its initial condition, ready for the next gas sample.

NOTE.—It is ordinarily maintained that considerable knowledge is required to under stand what the CO_2 recorder shows. This is not so. Post the CO_2 recorder conveniently for the fireman, let him know that the higher the CO_2 obtained the better fireman he is, and explain further that the higher the CO_2 the shorter will be the red line drawn by the recorder pen (or longer, depending upon the type of instrument). This is all that is necessary, except occasional suggestions on how to handle the fires to obtain a higher percentage of CO_2. In the next few weeks it will be surprising how the CO_2 will increase, especially if the firemen are placed in competition with one another by posting their results conspicuously upon a blackboard. The fireman himself will soon gain confidence, since he will see that when the fires are bad, the recorder pen strokes upon the chart will be long; when the fires are good, the ink lines will be short. It is important after he once gains this confidence that the recorders be kept in good condition and in proper operation; otherwise he will lose faith in the readings.



FIGS. 3,462 to 3,465.—Elementary CO_2 recorder illustrating operating cycle. Fig. 3,462 shows the initial position of the apparatus.

Fig. 3,462 shows an elementary apparatus for performing the four-part cycle just stated, and figs. 3,463 to 3,465, the manner in which the operations are performed.

The apparatus consists of two vessels, M, and S, suspended by cord from a pulley and connected with each other by a small rubber tube, as shown. M, is open at the top and S, is closed on top except for two openings, A, and B. At A, is a check valve connected by rubber tube to the flue gas sampling pipe, and at B, is another check valve and rubber tube connecting with a pipe leading into the gas bell.

The two vessels M, and S, and connections as described form a single acting pump, the capacity of S, being say 100 *cc.* As shown S, and the rubber tube are full of water, but when the pulley is turned counter-clockwise (by clock work not shown), S, will be elevated and M, lowered so that 100 *cc.* of flue gases will be sucked into S, as shown in fig. 3,463.

Now the clock work turns the pulley clockwise till the M, and S, come back to their original position. The water runs back from M, into S, and by aid of the check valves forces the measured sample of gas into the gas bell, which rises as shown in fig. 3,464 and by means of an arm and pencil records on the drum a line LR, whose length depends upon the amount of gas that is passed through the caustic potash solution (KOH) in the containing vessel.

Now if the gases contained no CO_2. the same volume of gas would be admitted to the bell, as was admitted to the measuring vessel S (fig. 3,463), or 100 *cc.*, and the recording pen would draw a line of length LF.

Again, if the gases contained say 8% CO_2, and this was absorbed in passing through the caustic potash solution, the volume of gas entering the bell would be decreased 12%, and the pencil would draw a shorter line, equal to 100—12=88% of LF. That is, calling F, zero and L, 100%, then the distance FR, *not* marked by the pencil, represents the percentage of CO_2, which in this case is 12%.

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*NOTE.—In the elementary apparatus just described the *longer* the line drawn by the pen the *less* the percentage of CO^2, but it should be noted that in some instruments the *longer* the line the *greater* the percentage of CO^2, this being due not to a different principle but to modified mechanical arrangement.

FIGS. 3,462 to 3,465.—*Continued.*

at beginning of the cycle. ***First operation:*** Pulley moves counter-clockwise and 100 cubic centimeters of the flue gases are taken into S, as in fig. 3,463; ***second operation,*** pulley moves clockwise fig. 3,464 and the measured sample is forced from S, through the caustic potash into gas bell, absorbing CO_2, elevating bell to height corresponding to diminished volume, and recording on drum the diminished volume; ***third operation,*** clockwork opens exhaust valve fig. 3,465 thus allowing bell to sink to its initial position. Each time the pulley moves clockwise the ratchet turns down slightly from right to left so that no two pen rounds will come in the same place on the paper chart attached to drum.

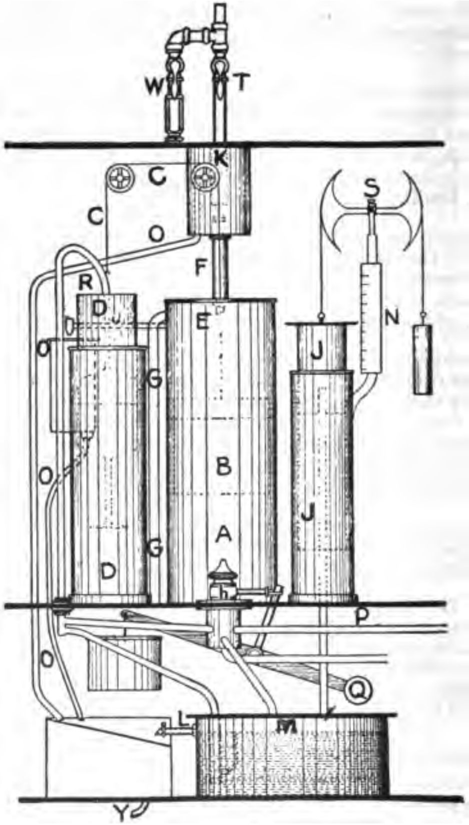


FIG. 3,466.—Simmance-Abady CO_2 recorder, showing whole of working parts in position except the clock and pen. Water is put into vessels D and J, and maintained at correct height by a constant level tank. ***In operation,*** water is allowed to flow through hollow valve stem E, from the small reservoir K, with the safety overflow OO. In syphon tank A, there is a weighted float B, which is attached by means of a chain E, to the bell D, of the extractor, and this float rises with the water, allowing the bell D, to fall. At the top of its stroke, the float B, raises the valve stem E, thus tripping the valve, and momentarily flushing the syphon tank; the water now syphons out of A, through syphon tube G, and allows the weighted float to fall. As it falls it draws up the water sealed extractor bell D, in which is created a partial vacuum, and into which, therefore, gas flows from the flue through P and H. This may be called the beginning of the cycle. Next, the weight of the water which has flowed from the syphon tube G, into the small pot beneath it, overcomes the weight of the counter Q, and closes the balance valve H, thereby cutting off a definite sample of the gas. Water is released from the small pot in time to allow the valve to open

In the gas bell container is an exhaust pipe which runs up to the surface of the liquid having at the other end a valve under control of an arm moved by the clock work.

In fig. 3,462 this valve is open so that all the previous sample can be exhausted into the atmosphere and the gas bell allowed to sink to the level of the liquid as shown.

In figs. 3,463 and 3,464 this valve is closed so that no gas will escape from the bell until after all the gas has been transferred from S, to the bell, thus permitting the bell to rise to the proper height and the pen to correctly record the percentage of CO_2.

After the record has been made as in fig. 3,464 the clock work opens the exhaust valve and the bell sinks to its initial position as in fig. 3,465, the pen drawing the vertical line FR, thus completing the cycle.

During the cycle each time the pulley moved clockwise the ratchet arm turns the drum from right to left a very small amount, thus the pen records are made progressively along a ruled paper card attached to the drum.

By ruling the card horizontally into a CO_2 percentage scale and vertically into a time scale, not only is the same CO_2 reading shown, but also the time at which they were made, assuming that the clockwork is so arranged that the ratchet will cause the drum to make a complete revolution in 24 hours.

FIG. 3,466.—*Text continued.*

at the proper interval. The stream of water is continually flowing into the tank A, and the float B, rises again, which allows the extractor bell D, to sink. As it sinks, it will be seen that the gas in bell D, (which by the closing of the valve H, is now uninfluenced by vacuum or other conditions in the flue), is first reduced to atmospheric pressure, and is then actually under pressure; the volume of the gas is, therefore, forced into vessel M, where it bubbles up through the caustic solution and CO_2 absorbed, and thence into the recorder J, raising the bell. The boxwood scale N, at the side of the recorder tank is graduated from 100 per cent. at the bottom to 0 per cent. CO_2 at the top, and the capacity of the bell D, is such that when the apparatus is run on air, containing practically no CO_2, the total volume is transferred to the recorder bell J, which in this case rises to the zero point. When flue gas is admitted to the apparatus, exactly the same quantity (*i.e.*, enough to send recorder bell up from 100 to 0) is passed from the extractor bell D, but on the passage of the gas, the CO_2 is absorbed by the caustic potash in iron vessel M, reducing the volume of the gas; owing to such absorption the recorder bell J, will not rise to its full height, giving line FR. It automatically rises as far as it will, and a pen then marks on a chart its final position. ***The percentage of CO_2 in the gas is thus automatically recorded.*** This bell J, then vents, discharging the analyzed gas through the three-way cock, so that it does not mix with or come in contact with the fresh charge of gas, which is dealt with in exactly the same way, the whole operation, as well as the continuous drawing forward of the flue gas, taking place automatically by means of the stream of water. For the purpose of bringing along a constant supply of gas, below the cock X, is an injector or aspirator, attached to the top of the case; P_1, is an auxiliary gas connection to the aspirator from the main inlet pipe P. ***By this means, gas is continuously exhausted from the pipes connecting recorder to boilers,*** so that the successive samples analyzed from the instrument are from the boiler flue, and not stagnant gases in the connecting pipes. The injector is worked by the small stream of water (the motive power for the recorder) connected at X, before this enters the top tank of the Recorder so that no extra water is used for this continuous pump. Two glass bottles are fixed in connection with the injector as safeguards. A glance at one shows whether the flue gas pipes are clear of obstructions and the other shows that the stream of gas is being maintained.

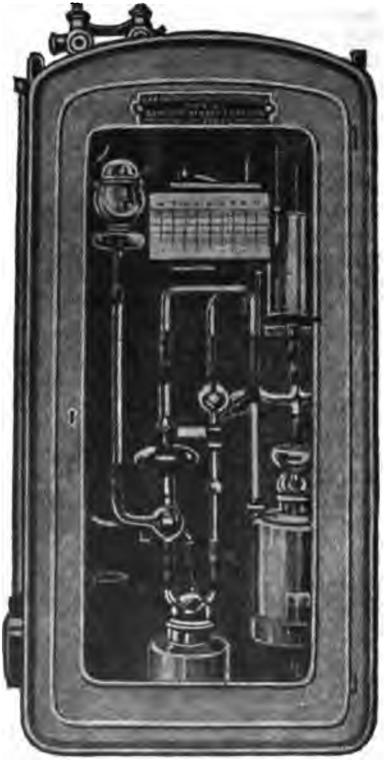


FIG. 3,467.—Sarco CO_2 recorder, type C (see outline diagram on page 1,940). The power required for operating is derived from a fine stream of water at a head of about 2 ft. The water flows through tube 74 into the power vessel 82, compressing the air above the water level and this pressure is transmitted to vessel 87 through tube 78. The pressure thus created in 87 forces the liquid in that vessel upward through tubes 91 and 93 into vessels 66, 67, 68 and 77. It rises until it reaches the O mark 71 on vessel 67, At the moment it reaches this mark, the power water, which simultaneously has travelled upward in syphon 72, reaches the top of the syphon and empties vessel 82, releasing the pressure in 87. Assuming tube 49 to be in connection with the flue gas, a sample is drawn in from the continuous stream which passes through 43, 45 and 46 by a partial vacuum created by the falling of the liquid in 49. As soon as the flow in the syphon stops, vessel 82 begins to fill again and the liquids in tubes 91 and 93 rise afresh. The gas in 67 and 68 is now forced up into tube 50 and caused to bubble through a solution of caustic potash in vessel 94. The carbon dioxide is absorbed and the remaining portion of the sample collects in vessel 62 and passes into tubes 57 and 58; thence it passes under the two floats 18 and 26, displacing same and causing a movement of the pen on the chart, exactly in proportion to the percentage of CO_2 in the respective gas sample absorbed by the caustic potash. This type of recorder permits of very rapid analysis of the gas, and up to 30 separate analysis can be recorded per hour.

NOTE.—***The draught gauge*** may be employed to great advantage in connection with the CO_2 Recorder. To burn a given quantity of a given coal per square foot of grate per hour requires a certain draught for each depth of coal on the grates, starting with a minimum draught just after cleaning fires when the fuel bed is thin and gradually increasing to a maximum when the fuel bed is thickest, just before the next cleaning period. With a recording draught gauge of the differential type (that is one to record the drop in pressure of the air in passing through the fuel bed) installed in connection with a CO_2 Recorder, the draught control in the majority of plants can be readily standardized. Observations should be taken of the draught which is required for the conditions obtaining at the end of each hour, after cleaning fires, up to the next cleaning period. The draught should be regulated so that with careful firing, such that fires are kept well covered, both burnt-out spots and blow holes being prevented, a CO_2 recorder will indicate about 40% excess air is passing through the furnace. In a comparatively short time sufficient information will be obtained in most plants to establish a draught line, starting at a minimum just after a cleaning, and rising steadily to a maximum just before the next cleaning. The fireman by then holding the draught to this grade line, can regulate his firing by the CO_2 Recorder. He will, of course, have continually to vary the draught above and below the draught grade line established, according to the fluctuations of load. If the water level in the boiler be properly maintained and the firing done with regularity, these variations from the draught grade line, in most plants, will be much smaller than anticipated. Standardizing the draught control in this manner will very much simplify the fireman's problems, and will not only increase his efficiency, but will decrease the severity of his work.

FIG. 3,467.—*Text Continued.*

has sealed the lower end of this center tube, exactly 100 cubic centimeters of flue gas are trapped off in the outer vessel C, and its companion tube, under atmospheric pressure. As the liquid rises further, the gas is forced through the thin tube and into vessel A, which is filled with a solution of caustic potash at 1.27 specific gravity. Upon coming into contact with the potash and the moistened sides of the vessel, the gas is freed from any carbon dioxide that may be contained in the sample, this being rapidly and completely absorbed by the potash. The remaining gas gradually displaces the potash solution in A, sending it up into vessel B. This has an outer jacket, filled with glycerine and supporting a float N. Through the center of this float reaches a thin tube, through which the air in B, is kept at atmospheric pressure. The float is suspended from the pen gear M, by a silk cord and counter-balanced by the weights X. The rising liquid in B, first forces a portion of the air therein out through the center tube in the float, and then raises the latter. This causes the pen lever to swing upwards, carrying pen with it. The mechanism is so calibrated and adjusted that the pen will travel right to the top, or zero line, on the chart when only atmospheric air is passing through the machine, and nothing is absorbed by the potash in A. Thus should any carbon dioxide be contained in the gas sample, it would be absorbed by the potash in A, not so much of this liquid would be forced up into vessel B, and the float would not cause the pen to travel up so high on the chart, in exact accordance to the amount of CO_2 absorbed. The tops of the vertical lines recorded on the chart, therefore, provide a continuous curve showing the percentage of CO_2 contained in the exit gases from the flues, on a permanent diagram arranged for 24 hours. When the liquid in C, has reached the mark on the narrow neck of that tube, the whole of the 100 cubic centimeters have been forced on to the surface of the potash, one analysis being thus complete. At this moment the power water, which, simultaneously with rising in tube H, has also traveled upwards in syphon G, will have reached the top of this syphon, which then commences to flow. Through syphon G, a much larger quantity of water is disposed of than flows in through the cock, so that the power vessel K, is rapidly emptied again. The moment the pressure on this vessel is released, the liquid from C, returns into the lower compartment, and float N, to its original position. As soon as the liquid in C, has fallen below the gas in and outlets to this vessel, the whole of the remaining gas is rapidly sucked out through E, by the powerful ejector Q. The vessel F, is provided with a small center tube, open to atmosphere, and this serves as an indication that the pipe line is clear, the ejector drawing air through the sea. in the case of stoppage. The instrument, once erected, works entirely automatically, and requires no attention whatever, beyond changing of the chart and winding of the clock every 24 hours, and renewal of the potash solution every 14 days to 3 weeks.

CO_2 and Fuel Losses.—The CO_2 percentage indicates the volume of excess air flowing through the furnace, and the power of the boiler; it is the ratio between the air that is taken for a useful purpose in burning the coal and that which is taken to the wasteful end of cooling the furnace gases. That is all it does indicate and its indications are only approximations.

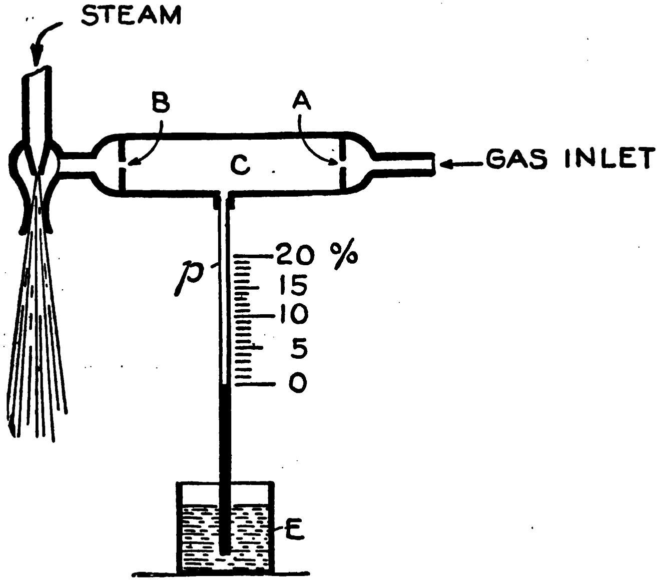


FIG. 3,468.—Diagram illustrating working principle of Uehling CO_2 recorder: ***Measurement is made by changes in the partial vacuum in chamber C, to which can be connected both indicators and recorders, which may in turn be located where desired.*** The gas to be analyzed is drawn through two apertures A, and B, by a constant suction produced by an aspirator. If the aperture be kept at the same temperature, the suction or partial vacuum in the chamber between the two apertures will remain constant so long as all the gas passes through both apertures. If, however, part of the gas be taken away or absorbed in the space between the two apertures, the vacuum will increase in proportion to the amount of gas absorbed. It is evident that if a micrometer or light vacuum gauge be connected with this chamber, the amount of gas absorbed will be indicated by the vacuum reading.

The air excess could be determined much more accurately by finding the percentage of free oxygen with an analyzer.

The objection to the oxygen analysis is that it takes time and there is not enough time for it. Speed is essential and some of the data will be lost unless the analyzer be worked about once a minute. It will take five minutes to determine the oxygen.

When the CO_2 percentage has been worked up to 12 or 15 by improving the firing methods, it will then be time enough to analyze for oxygen and CO.

Numerous charts and tables have been prepared to show the CO_2 and excess air relations and it must be remembered that all such charts and tables are based upon an assumed set of conditions.

In the accompanying tables the fuel is assumed to be pure carbon,

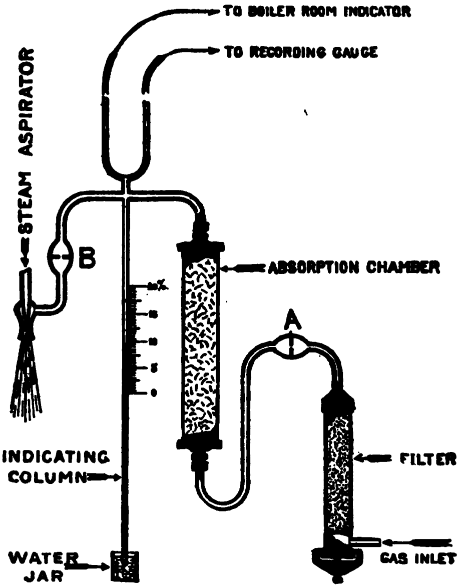
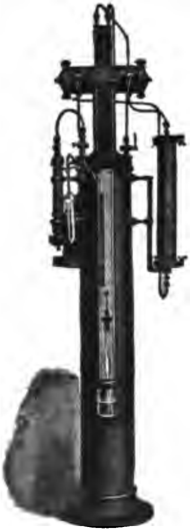


FIG. 3,469.—Diagram of the more important parts of Uehling CO_2 recorder, showing path of the gases through the filler, apertures and absorption chamber. The recorder consists primarily of a filter, dry absorber, two apertures A and B, and a small steam aspirator. Gas is drawn from the last pass or uptake of the boiler by means of the aspirator through a preliminary filter located at the boiler, and then through a second filter on the instrument as shown. Besides these filters, auxiliary filters are supplied before each aperture, which insure the gas flowing through the apparatus being clean. The clean gas passes through aperture A, thence through the absorption carton and aperture B, to the aspirator, where it leaves the instrument with the exhaust steam. Between the two apertures is a carton containing an absorbent called natron. Each carton will last about a week and may be replaced by removing cap on carton chamber by unscrewing wing nuts. The column of water which measures the partial vacuum between apertures A and B, is calibrated directly in per cent. of CO_2. This vacuum or per cent. CO_2 is also communicated to the recording gauge and boiler room indicator, both of which can be located at a considerable distance from the machine proper.



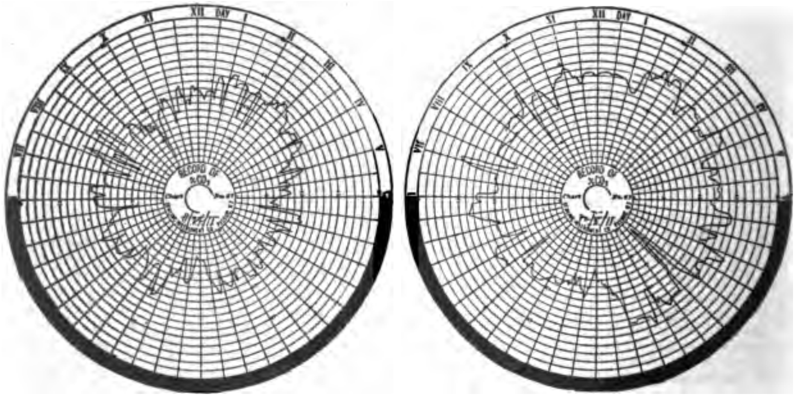
and the stack temperatures are assumed to be constant at 500°F.; neither of these conditions actually obtain.

The higher the stack temperature, the hotter is the excess air being heated, and the hotter it is, the greater the amount of fuel being wasted.

The engineer is not supposed to compute his gains and losses from the accompanying tables, for the table applies to pure carbon only. With such fuel the theoretical CO_2 would be 20.7% by volume, but when a bituminous coal for instance is burned, the theoretical CO_2 will be less, depending upon the percentage of hydrogen in the combustible, probably somewhere between 17% and 19%.

The fuel waste then in any particular plant may be more or less than the figures given in the table, but they are sufficiently approximate to serve as a guide for all practical purposes, and may be used as a basis for a bonus system for the firemen according to the CO_2 results obtained by them.

FIG. 3,470.—Uehling CO_2 machine mounted on central column. *It consists of* a cast iron heading and wrought iron cylindrical regulator, on which are mounted and properly assembled, the necessary filters, absorption chambers and the adjusting cocks, as shown. All connections are brass and copper tubes.



FIGS. 3,471 and 3,472.—Two CO_2 charts from a Uehling CO_2 recorder installed in a New England plant. The chart fig. 3,471 was obtained shortly after the installation of the recorder when the per cent CO_2 (as averaged from the chart) was 8.48 per cent and coal consumption 11 tons per day. The second chart fig. 3,472, obtained a few weeks later shows 11.75 per cent CO_2 and the coal consumption was 10 tons per day.

CO_2 and Fuel Losses.

(for pure carbon and 500°F. stack temperature

According to Hays

Pct. CO_2	Pct. preventable Fuel Loss	Pct. CO_2	Pct. preventable Fuel Loss	Pct. CO_2	Pct. preventable Fuel Loss
15.	.0	10.	5.69	5.	22.79
14.8	.148	9.8	6.04	4.8	24.21
14.6	.305	9.6	6.4	4.6	25.76
14.4	.47	9.4	6.78	4.4	27.44
14.2	.635	9.2	7.18	4.2	29.29
14.	.808	9.	7.58	4.	31.28
13.8	.99	8.8	8.02	3.8	33.58
13.6	1.17	8.6	8.47	3.6	36.08
13.4	1.36	8.4	8.95	3.4	38.87
13.2	1.54	8.2	9.44	3.2	42.01
13.	1.75	8.	9.66	3.	45.28
12.8	1.95	7.8	10.51	2.8	49.64
12.6	2.16	7.6	11.09	2.6	54.34
12.4	2.38	7.4	11.7	2.4	60.32
12.2	2.6	7.2	12.34	2.2	66.3
12.	2.84	7.	13.02	2.	74.
11.8	3.08	6.8	13.74	1.8	83.56
11.6	3.33	6.6	14.49	1.6	95.45
11.4	3.59	6.4	15.3	1.4	
11.2	3.86	6.2	16.16	1.2	
11	4.13	6.	17.09	1.	
10.8	4.43	5.8	18.06	.8	
10.6	4.72	5.6	19.12	.6	
10.4	5.03	5.4	20.25	.4	
10.2	5.35	5.2	21.47	.2	

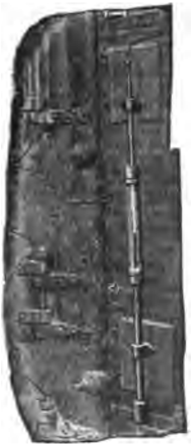
CO_2 AND AIR EXCESS

(*According to Hays*)

Percentage CO_2	Percentage air excess	Percentage CO_2	Percentage air excess
15	38	7	158.7
14	47.8	8	195.7
13	59.2	6	245
12	72.5	5	314
11	88.1	4	417
10	107.	3	590
9	130.	2	935
		1	1970

To determine the percentage of excess air for any given percentage of CO_2, as for example 5.4%, subtract the observed percentage 5.4, from 20.7; divide the remainder by the observed percentage and multiply by 100. This gives the volume of excess air. At 5.4% CO_2 the excess air is 283.33%.

Roughly the preventable fuel waste may be computed by allowing 1% fuel loss for each 12.11% of air excess above 38%. This figure according to Hays is quite as accurate as the one commonly applied to feed water, that is, 1% gain per increase of 10°F. in the temperature of the feed water.



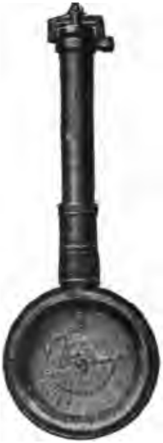


FIG. 3,473.—Uehling auxiliary boiler room (CO_2) indicator. This permits locating the machine proper and recorder outside of the boiler room, without depriving the firemen of the benefit of the equipment.

FIG. 3,474.—Uehling CO_2 recording gauge. *It operates* on the hydrostatic principle, by which all spring levers or joint movements are avoided. The gauge is designed for an 8-inch circular chart ruled for 0 to 20 per cent CO_2 and making two revolutions in 24 hours. The gauge is connected by drawn copper tubing to the instrument and can be mounted at a distance from same, as, for instance, in the chief engineer's office.

CHAPTER 61

CLASSIFICATION OF BOILERS

The great variety of boilers now in use is due to the many different kinds of service for which they are intended, the varied conditions accompanying their use, and the competition among engineers who have sought to produce, at moderate cost, boilers that will be safe, durable compact and economical.

Any classification, to be comprehensive, should be made from numerous points of view. Accordingly, boilers may be classified:

1. With respect to service (broadly speaking), as

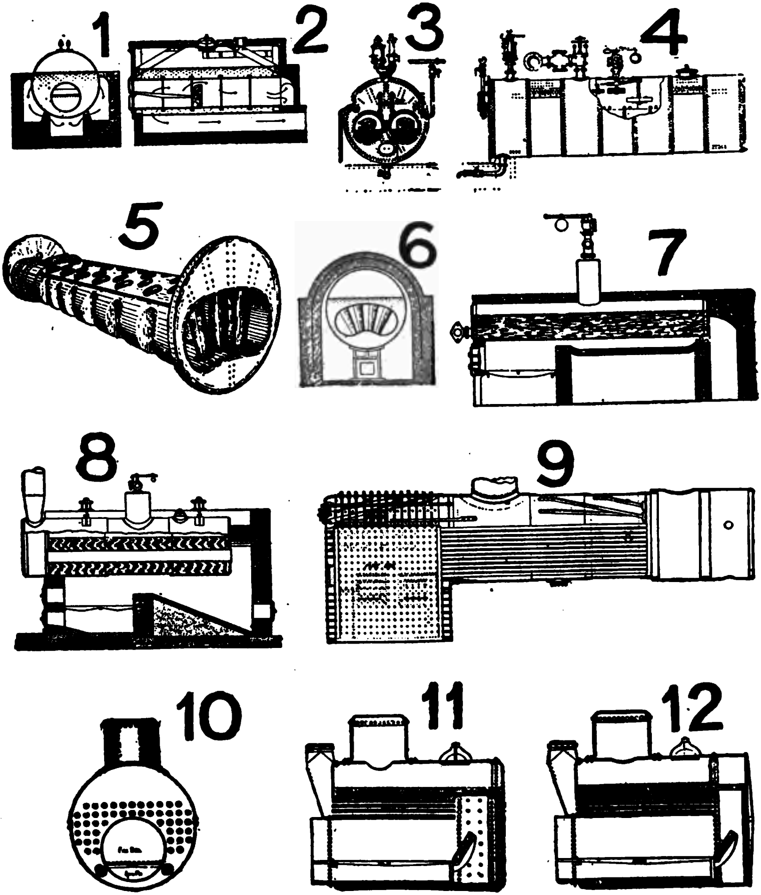
a. Stationary {
  heating
  power
b. Locomotive
c. Marine

2. With respect to the type of furnace, as

a. Internally fired
b. Externally fired

3. With respect to the character of the heating surface, as

a. Single flue;
b. Two flue, etc.;
c. Galloway tube;
d. Multi-tubular;
e. Pipe.



FIGS. 3,475 to 3,486.—Various shell boilers. 1 and 2, ***Trevithick*** or so-called Cornish; 3 and 4, Lancashire; 5 and 6, Galloway, showing breeches and Galloway tubes; 7, plain cylindrical; 8, one flue; 9, dry bottom firebox locomotive; 10 and 11, Scotch or water back; 12, Clyde or dry back.

4. With respect to the heat absorbing surfaces of the tubes, as

- *a.* *Fire tube;*
- *b.* *Water tube;*
- *c.* Combination fire and water tube.

5. With respect to special features of the tubes, as

- *a.* Single tube;
- *b.* Double tube (Field type);
- *c.* Through tubes;
- *d.* Submerged tubes;
- *e.* Radial tubes (porcupine type).

6. With respect to the shape of the tubes, as

- *a.* Straight;
- *b.* Curved;
- *c.* Coiled.

7. With respect to the position of the tubes, as

- *a.* Horizontal;
- *b.* Inclined;
- *c.* Vertical.

8. With respect to the grouping of the tubes, as

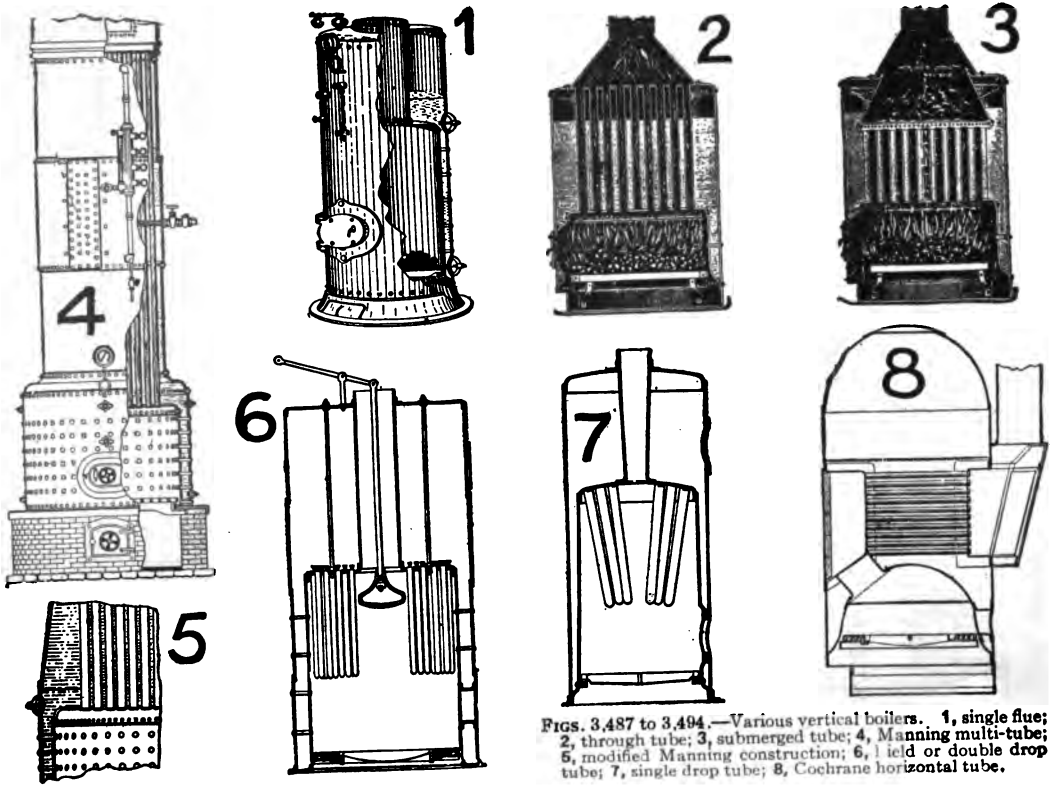
- *a.* Sectional;
- *b.* Non-sectional.

9. With respect to the liberating surface, as

- *a.* Water level;
- *b.* Semi-flush.
- *c.* Flash.

10. With respect to the flow of the products of combustion, as

- *a.* Single flow;
- *b.* Return flow;
- *c.* Triple flow.



FIGS. 3,487 to 3,494.—Various vertical boilers. **1**, single flue; **2**, through tube; **3**, submerged tube; **4**, Manning multi-tube; **5**, modified Manning construction; **6**, Field or double drop tube; **7**, single drop tube; **8**, Cochrane horizontal tube.

11. With respect to the number and placement of the furnaces, as

a. Single;
b. Double, etc.;
c. Single ended;
d. Double ended.

12. With respect to the shape of the furnace

a. Rectangular (stayed);
b. Cylindrical;
c. Corrugated.

13. With respect to the type of combustion chamber, as

a. Water-back (***Scotch*** type);
b. Insulated back (***Clyde*** type).

14. With respect to the shape of the shell, as

a. Haystack or balloon (early type);
b. Plain;
c. Saddle.

15. With respect to the degree of steam pressure, as

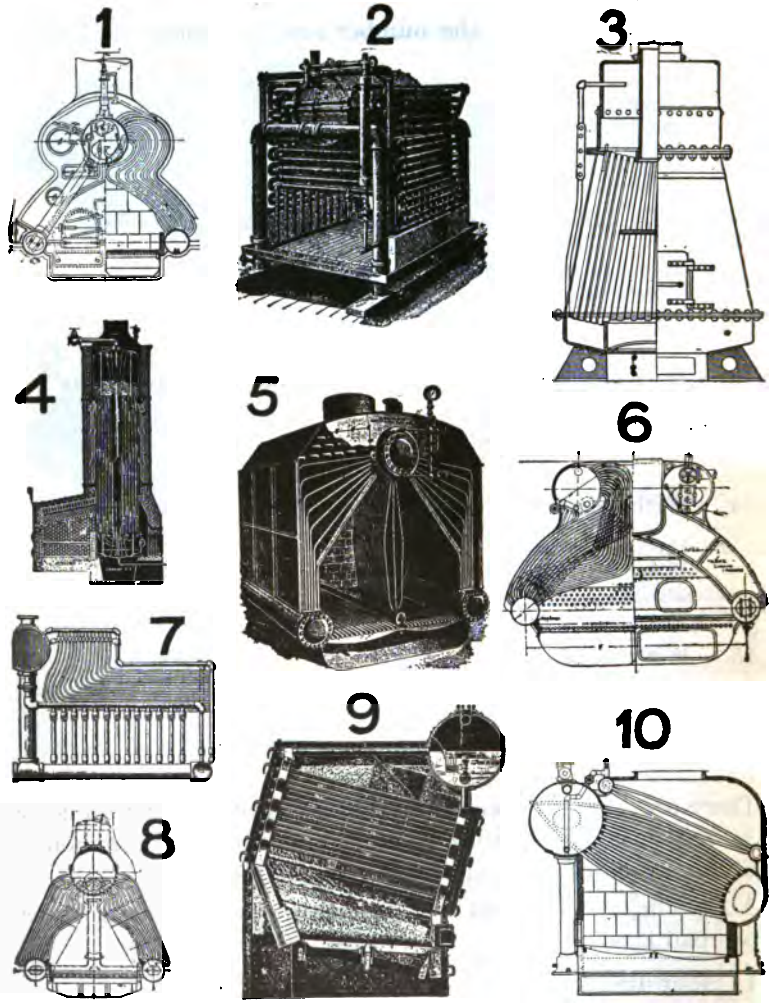
a. Low pressure;
b. Medium pressure;
c. High pressure.

There are, as can be seen from the classification, a multiplicity of boiler types, and because of numerous features in common, a really satisfactory division of the types is difficult.

A classification adopted by Gunsaulus, divides boilers under two broad heads:

1. According to use.
2. According to form of construction.

This tabulation will be helpful to properly place the various forms.



Figs. 3,495 to 3,504.—Various water tube boilers. 1, Thornycroft; 2, Roberts; 3, Watson; 4, Cook; 5, Seabury; 6, Mosher (double steam drum); 7, Boyer; 8, Normand; 9, Babcock and Wilcox; 10, Mosher (single steam drum).

CLASSIFICATION OF BOILERS.

1. According to Use.

Stationary

- Early forms
- Plain cylindrical
- Single flue, external flue
- Flue boilers
  - Cornish (single flue)
  - Lancashire (two flue)
  - Galloway
- Multi-tubular
  - externally fired
  - internally fired
- Fire box
  - horizontal
  - vertical
- Water tube boiler
  - straight tube
  - curved tube
  - horizontal
  - vertical
  - sectional
  - non-sectional
- Mixed type
- Peculiar forms

2. According to form of Construction.

Early Forms

Flue

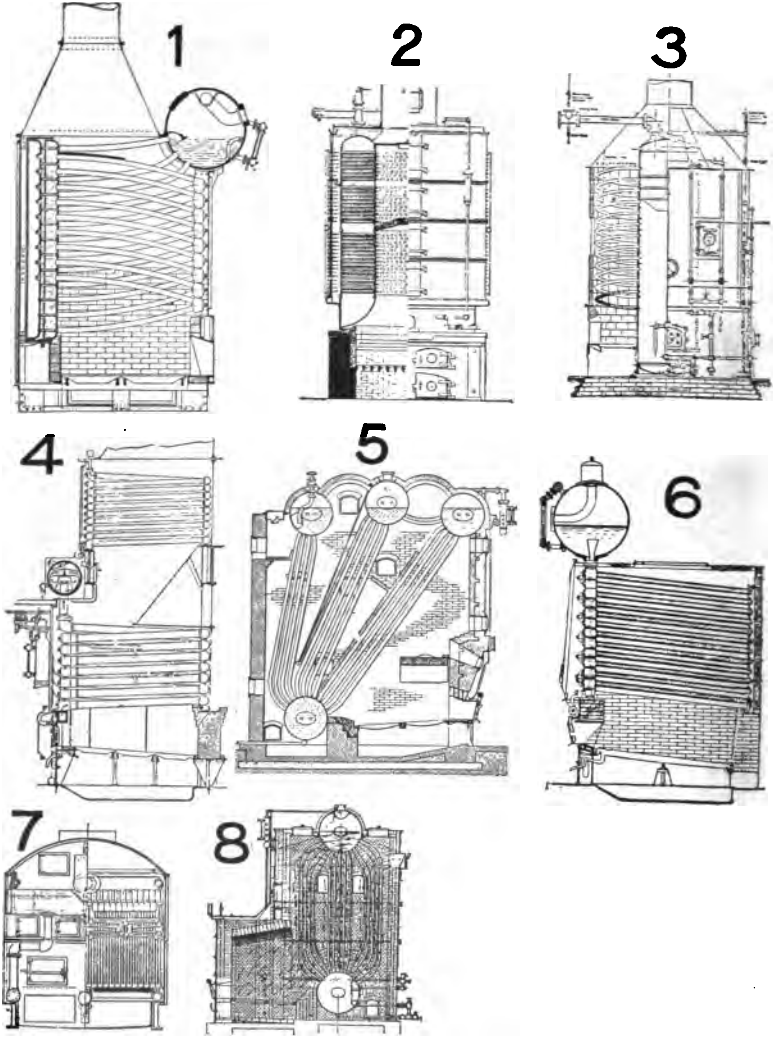
- Cornish (single flue)
- Lancashire (two flue)
- Galloway
- Single flue (externally fired)

Fire Tube

- Horizontal (curved form)
- Vertical
- Return tube
- Through tube
- Fire box
- Peculiar forms

Water Tube

- Horizontal
  - straight tube
    - sectional
    - non-sectional
  - curved tube
- Vertical
  - straight tube
  - curved tube
- Peculiar forms

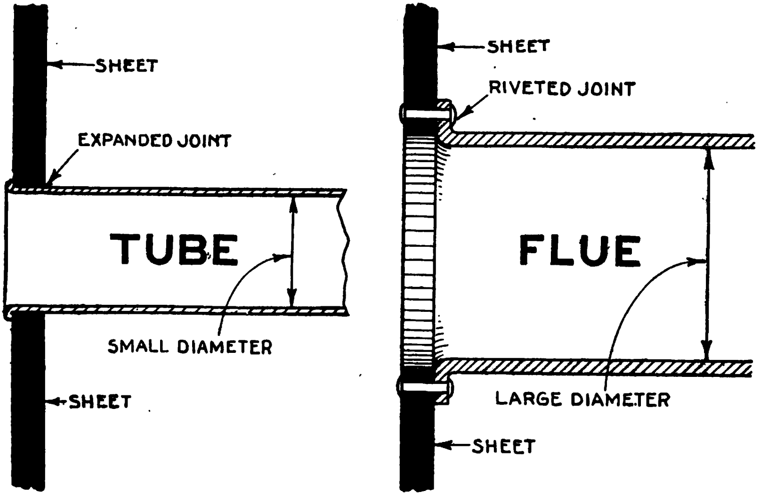


FIGS. 3,505 to 3,512.—Various water tube boilers. 1, Marshall-Thornycroft; 2, Berry; 3, Morrin's "Climax"; 4, Belville; 5, Stirling; 6, Niclausse; 7, Almy; 8, Milne.

Mixed Types

Marine
- Early forms (box or rectangular)
- Scotch or drum
- Return tube
- Through tube
- Water tube
  - curved tube
  - straight tube
  - sectional
  - non-sectional

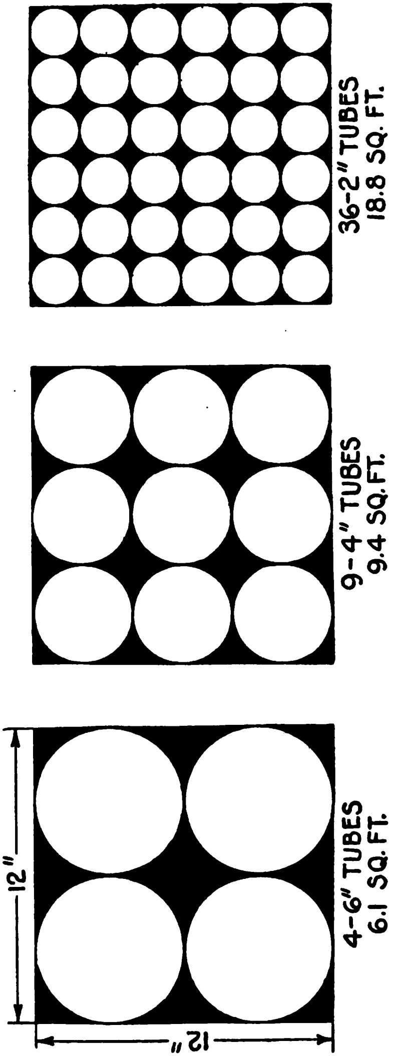
Locomotive
- Multi-tubular fire box
- Wooten type
- Corrugated furnace
- Peculiar forms



FIGS. 3,513 and 3,514.—Differences between a tube and a flue. The chief differences are sizes and method of making the joint as by expanding and riveting as shown.

Ques. What is the difference between a tube and a flue?

Ans. A tube is a lap welded or seamless cylindrical shell made in small sizes up to and including 6 inches diameter. A flue is a large cylindrical shell made in sizes from 7 inches to 18 inches diameter, it may be seamless, lap welded, or riveted.



FIGS. 3,515 to 3,517.—*Characteristics of tubular heating surface: The smaller the tube the greater the amount of heating surface that can be put in a given shell.* In the figures let the rectangle represent a square foot of the tube sheet. Evidently there can be placed within the rectangle 4 6-inch tubes, 9 4-inch tubes, or 36 2-inch tubes, giving respectively 6.1, 9.4, and 18.8 square feet of heating surface per foot length of tubes, thus illustrating the increase in heating surface as the size of tube is decreased. *Of course in practice the tubes do not touch each other but a margin of metal is interposed for strength and tight joints.* While this modifies the results obtained somewhat the law given above holds.

In England the term flue is erroneously used in the same sense that tube is used in America.

Ques. What is the difference between a flue and a tubular boiler?

Ans. A flue boiler, has two or three flues, whereas a tubular boiler has a multiplicity of tubes.

Ques. Why have flue boilers practically gone out of use?

Ans. Because considerably more heating surface can be provided within a shell of given size by using a large number of tubes closely spaced, notwithstanding the excessively long length of some flue boilers.

Ques. What is the difference between a fire tube and a water tube?

Ans. A fire tube is one in which the products of combustion pass through the tube which is surrounded by water. A water tube is surrounded by the products of combustion, the water being inside the tube.

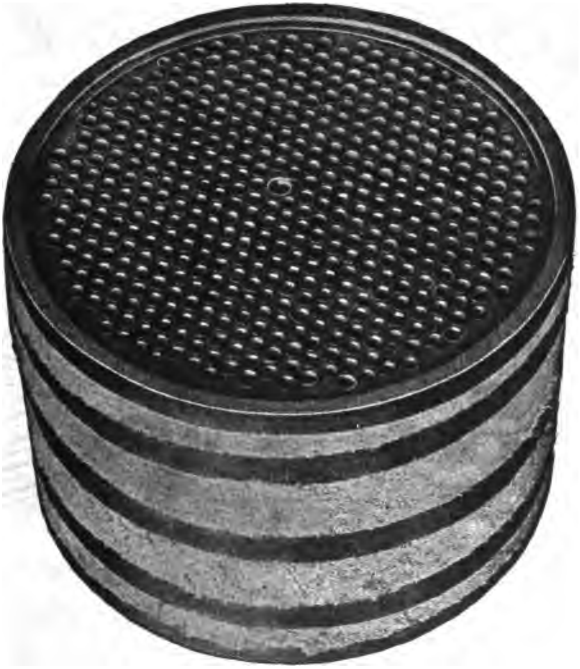
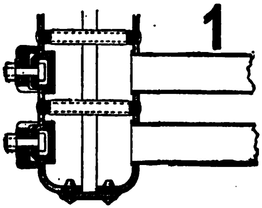
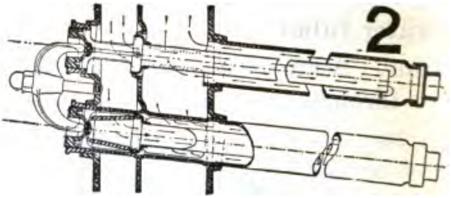
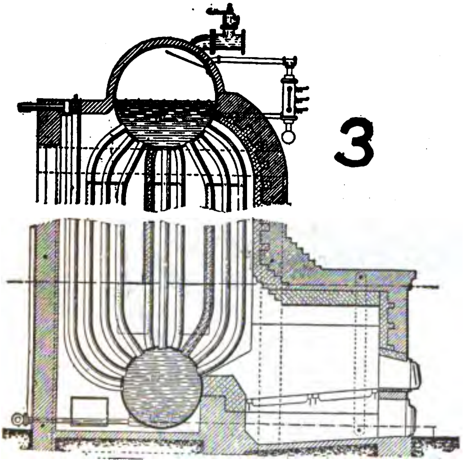
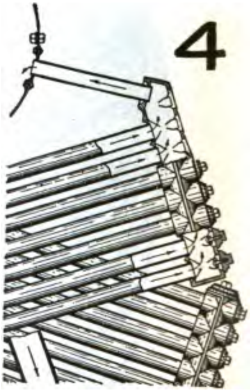


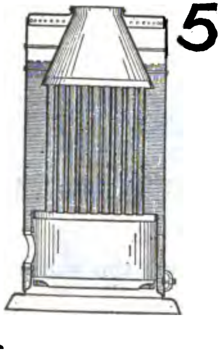
FIG. 3,518.—Stanley automobile boiler illustrating the very large amount of heating surface that can be put in a small shell by using very small tubes. The tubes are $\frac{33}{64}$-inch diameter by 14 inches long, excepting those in the 26-inch boilers which are 16 inches long. In the 18-inch boilers there are 469 tubes with 66 square feet of heating surface. In the 23-inch boilers there are 751 tubes with 104 square feet of heating surface. In the 26-inch boilers there are 999 tubes with 158 square feet of heating surface. ***Approximate weights*** 14 inch boiler 112 lbs.; 23 inch 293 lbs., or about 10% of the weight of ordinary vertical shell boiler of same capacity.

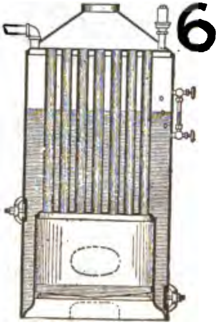












FIGS. 3,519 to 3,524.—Various tube arrangements as explained in the accompanying text. **1**, single tube; **2**, double tube; **3**, non-sectional; **4**, sectional; **5**, submerged tube; **6**, through or flush tube.

Ques. What is a single tube boiler?

Ans. One made up of plain tubes.

Ques. What is a double tube boiler?

Ans. One having an auxiliary tube placed inside each main tube in order to promote circulation.

Ques. What is a Field tube?

Ans. The term Field tube is another name for a double tube, so called because it was invented by Field.

The arrangement consists of two concentric tubes which greatly improves the circulation and steaming capacity of a vertical boiler, the weight and cost being also increased.

In operation, the heated water rises in the annulus between the inner tube and the exterior heating surface, while the cold water circulates down the inner tube. A Field tube is also called a ***drop tube*** because it usually projects downward from a tube sheet above, although in some cases the tubes are placed horizontally.

Ques. What is a non-sectional boiler?

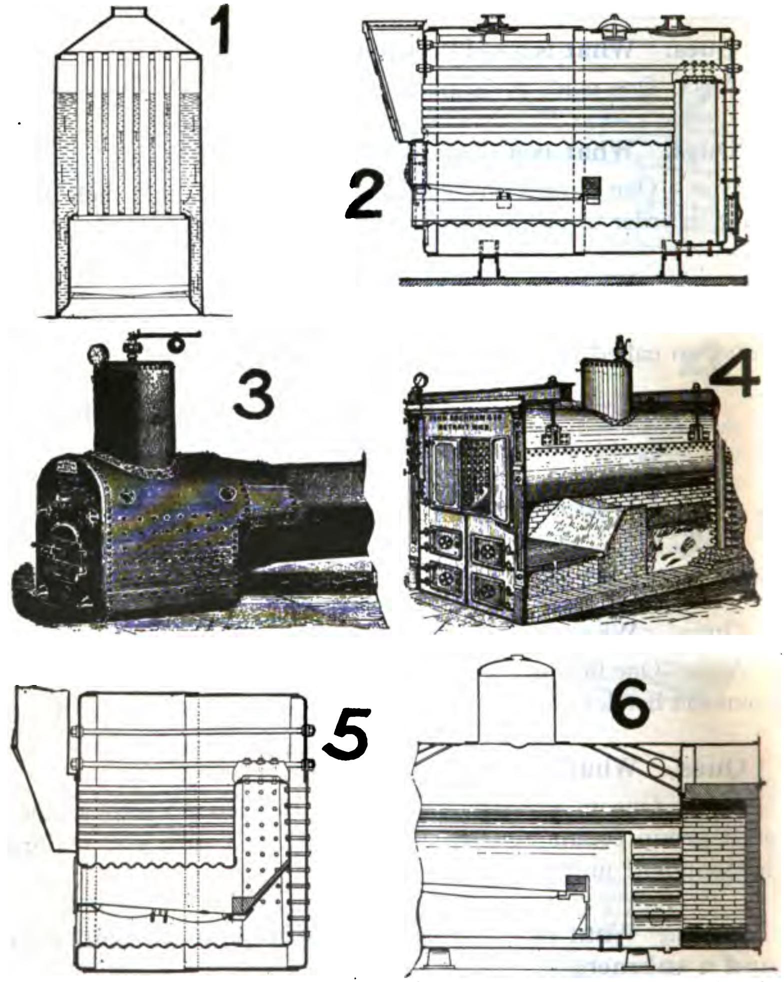
Ans. One in which all the tubes are in communication with a common header at each end.

Ques. What is a sectional boiler?

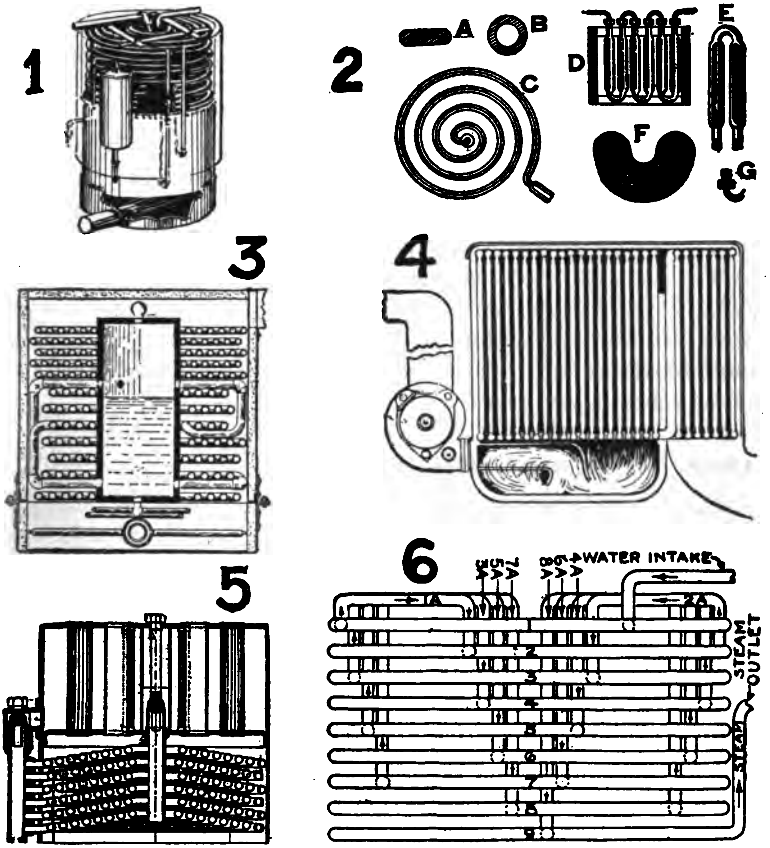
Ans. One in which the tubes are divided up into groups, each group communicating with a header at each end making independent units.

Ques. What is the difference between a through tube and a submerged tube boiler?

Ans. A through tube extends from the lower tube sheet the full length of the shell. A submerged tube terminates at its upper end below the water line.



FIGS. 3,525 to 3,530.—Various forms of combustion chamber arrangements as explained in the accompanying text. **1,** vertical cylindrical internally fired; **2,** horizontal corrugated furnace with water back combustion chamber; **3,** wet bottom fire box furnace of portable locomotive type; **4,** externally fired furnace, horizontal return tubular; **5,** horizontal corrugated furnace with water back (Scotch boiler); **6,** horizontal cylindrical furnace with tubular section and dry back.



FIGS. 3,531 to 3,536.—Various automobile boilers. 1. Lane combination flash and shell boiler; 2. (A to G) Serpollet flash generator (fig. A to C, earliest form, figs. D to G, second form); 3. Walker semi-flash generator; 4. Doble flash generator; 5. Geneva combination fire tube and water tube boiler; 6. White flash generator. ***Flash generation of steam*** should interest every steam engineer. In flash generators there is but a very small quantity of water and steam in the generator at any given moment, but the process of making steam is so rapid that the rate of steam production follows the changes in the intensity of the fire without any appreciable lapse of time. ***Tests*** on the White generator (by Prof. Carpenter) showed an evaporation of 13 lbs. of water per hour per sq. ft. of heating surface. It remains for some genius to develop the flash system commercially, and considering the many inherent defects of ordinary boilers it is surprising that so little attention has been given to the problem of flash steam generation.

Ques. What is a fire box boiler?

Ans. One having the fire within a fire box which, although external to the shell, is rigidly connected to it.

The fire box is usually made of steel plates instead of brick.

Ques. What is the difference between a Scotch and a Clyde boiler?

Ans. A Scotch boiler is one in which the combustion chamber is entirely surrounded by water. A Clyde boiler has, instead of a water space at the back end of the combustion chamber, a removable back which is lined with some insulating material such as asbestos or fire tile.

Ques. What are Galloway tubes?

Ans. Cross tubes placed in a flue and attached to opening in the side of the flue to increase the heating surface.

Ques. What is the difference between a Cornish and a Lancashire boiler?

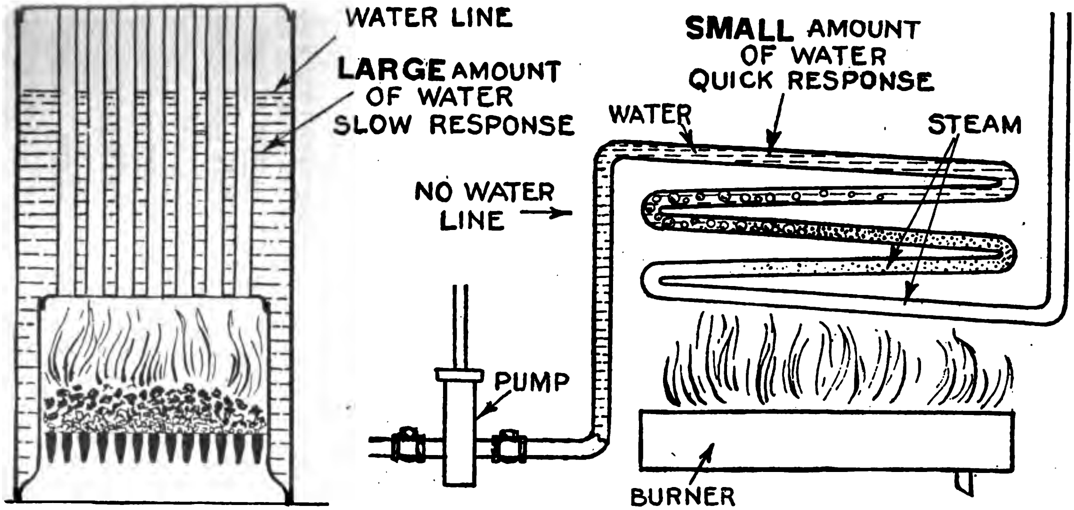
Ans. These are respectively one, and two flue boilers.

Ques. What is a return tubular boiler?

Ans. One so arranged that the products of combustion after passing along the length of the shell *return* in an opposite direction through the tubes before passing up the stack.

Ques. What is a porcupine boiler?

Ans. One having a vertical central drum into which are screwed a multiplicity of horizontal short tubes which project radially and having their outer ends closed and of square section which enables them to be screwed into the drum with a wrench.


WATER LINE
LARGE AMOUNT OF WATER SLOW RESPONSE
NO WATER LINE
PUMP
SMALL AMOUNT OF WATER QUICK RESPONSE
WATER
STEAM
BURNER

FIGS. 3,537 and 3,538.—Difference between a boiler and a generator. Fig. 3,537, boiler; fig. 3,538, generator.

In some forms a flat vertical tube sheet is used instead of a central drum.

Ques. What is an internally fired boiler?

Ans. One in which the furnace is within the shell, being surrounded by water.

Ques. What is an externally fired boiler?

Ans. One in which the furnace is outside the shell, the furnace walls being usually of brick.

Ques. What is the difference between a tube and a pipe?

Ans. The metal of a tube is thin, being proportioned only to withstand the steam pressure, whereas a pipe is made of relatively thick metal with threaded ends.

Tubes are intended for expanded joints (although in some porcupine boilers they are provided with fine threaded joints), whereas pipes are for threaded joints the extra thickness being provided for the rather coarse, Briggs threads.

Ques. What is the difference between a boiler and a generator?

Ans. A boiler carries a considerable volume of water in proportion to its heating surfaces, and is therefore not very sensitive to sudden changes in the rate of combustion, whereas a generator carries no excess volume of water but converts the water into steam as it transverses the heating surface progressively from one end to the other; it has no water level as indicated by water gauge or gauge cocks.

Ques. Name two types of generator?

Ans. Semi-flash and flash.

A semi-flash generator is a combination of a shell and flash boiler. It consists of a drum or shell holding a body of water and a coil of pipe forming the heating surface.

A flash generator consists of a long length of tubing formed into a coil, usually water entering at the top and being "flashed" into steam at some intermediate point coming out of the lower layer as superheated steam.

The term boiler is frequently used in place of generator.

CHAPTER 62

CHARACTERISTICS OF BOILERS

Ques. What duty does a boiler perform?

Ans. It transfers heat from the gases of combustion to water contained in the boiler, and converts the latter into steam usually under pressure greater than that of the atmosphere.

Ques. What means is provided for the transfer of heat?

Ans. Heating surface.

Ques. What are the essential qualities of the heating surface?

Ans. It must 1, absorb the heat of the burning gases as completely as possible, and 2, keep the water and steam from coming into direct contact with the fire.

Ques. What should be the nature of the material composing the heating surface?

Ans. It should, 1, be a good conductor, and 2, have ample strength to retain the steam under pressure even if heated to a high temperature.

Ques. What material is best adapted to the purpose, and why?

Ans. Iron, in general, or in the special form of steel, as it is a fairly good conductor of heat and has great strength, besides being obtainable in unlimited quantities at a low price.

Ques. What is the best form for the heating surface, and why?

Ans. The tubular form, because it gives maximum strength.

That is, it is the form giving the least weight per square foot of heating surface, lightness being especially desirable in marine practice.

Ques. How long should the gases be in contact with the heating surface?

Ans. Until cooled to such an extent that active and quick transmission of heat stops.

This is assumed to occur when the gases have reached a temperature of from 600 to 800°F.

Ques. How extensive should the heating surface be?

Ans. It should be large enough to effectually reduce the temperature of all gases, the size in square feet being regulated according to the number of pounds of fuel, from which the gases are developed.

Ques. Where are these gases developed from the fuel?

Ans. On the grate.

Ques. What is the function of the grate?

Ans. Its object is to provide sufficient space for a thin layer of the fuel so that the air has easy and uniform access to it, thus rendering combustion as near perfect as possible.

Ques. What should be the dimensions of the grate to effect the spreading of the fuel to best advantage?

Ans. The grate should be wide rather than deep, as this will allow the fireman to spread the fuel in nearer uniform thickness, and keep it in better condition for complete combustion.

Ques. What determines the number of pounds of fuel that can be burned?

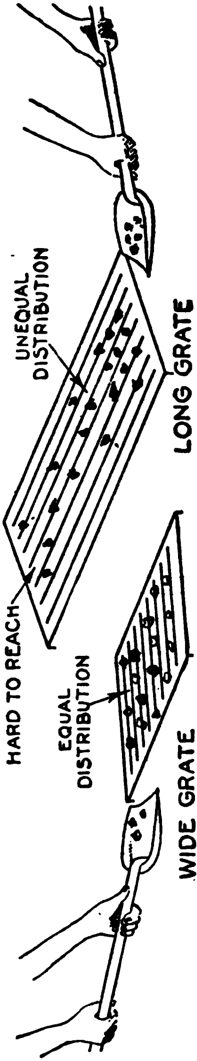
Ans. The area of the grate and the draught.

Ques. How are the heating surface and the grate area measured?

Ans. In *square feet.*

Ques. What is the ratio between heating surface and grate area?

Ans. The number of sq. ft. of heating surface per sq. ft. of grate area.



FIGS. 3,539 and 3,540.—Effect of the shape of the grate on firing. With a wide grate as in fig. 3,539, the coal is distributed uniformly without difficulty, but with a long grate as in fig. 3,540, special effort is required to reach the far end, hence in firing on this kind of grate the tendency is to pile up the coal at the near end and fire too thin at the far end, unevenly distributing the coal.

NOTE.—***The heating surface*** of a boiler is *that part of the boiler* ***exposed*** *to the heat generated by the furnace;* it is (with respect to the tubes) *the* ***internal surface of fire tubes*** *and the* ***external surface of water tubes.*** The area of heating surface is frequently used to express the horse power. This is figured from the number of square feet of boiler and tube surface, exposed to the action of the fire; the extent of the heating surface of a boiler depends on the length and diameter of the shell and the number and size of the tubes or flues. For the ordinary tubular boiler, fifteen square feet of heating surface has been held to be equal to one horse power; it is also customary in calculating the heating surface of the shell, to consider that two-thirds of it is exposed to the action of heat. For internal firebox boilers twelve square feet heating surface is usually allowed per horse power.

The ratio of heating surface to grate area varies widely according to conditions. With very low rates of combustion it may be say 1 to 20, and for very high rates as in locomotive practice, as much as 1 to 75 or more. ***In general,*** with ordinary rates of combustion, the ratio of heating surface to grate area varies usually between 30 to 1 and 40 to 1, because it has been found that the heat of the gases produced from the fuel on one square foot of grate area can be effectively and economically absorbed by from 30 to 40 square feet of heating surface.

Ques. What part of the heating surface is most effective in the transmission of heat, and why?

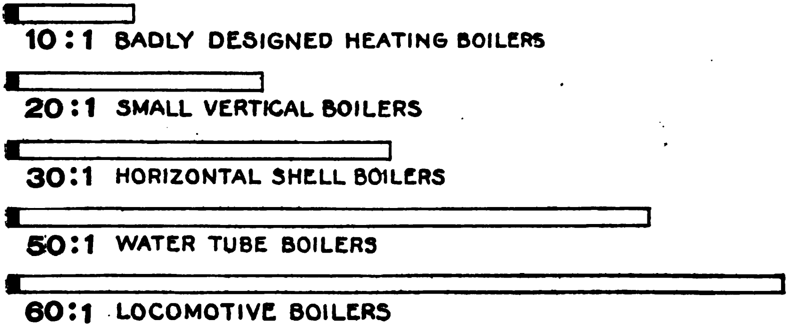


FIG. 3,541 to 3,545.—Various proportions of grate and heating surface in common use. Where economy is of any importance, 20:1 is about the lowest rating that should be used. Heating boilers as made by some manufacturers having only 10 sq. ft heating surface per sq. ft. of grate *will not be accepted by anyone of ordinary intelligence.*

Ans. The part of the heating surface nearest the fire, because at that point the differences in temperature of gases and water are the greatest, and, therefore, the absorption of heat is the quickest.

Ques. How is the transmission of heat by the heating surface measured?

Ans. By the number of pounds of water evaporated per square foot of heating surface per hour.

Ques. What are average rates of evaporation per square foot of heating surface?

Ans. For natural draught, about three pounds per hour. For forced draught, up to seven or more pounds of water per square foot of heating surface per hour.

Ques. How is the efficiency of evaporation affected by the different rates, and why?

Ans. The efficiency of evaporation is higher at low rates, because the heat is more completely absorbed.

In practice, however, it is not found profitable to go below average rates of evaporation, as a boiler, to produce a certain amount of steam, would have to be much larger and more expensive, if worked with low rates, than with high rates of evaporation.

Ques. How should the gas passages be arranged?

Ans. They should be so arranged that the whole heating surface can readily absorb heat of the gases.

Ques. What determines the size of the gas passages?

Ans. The area of the grate.

The ratio between them is usually one square foot of passage for a total of from seven to nine square feet of grate.

Ques. What is the ratio of the air space area of the grate to the total area of the grate and to the area of passages?

Ans. The area of the air space is from one-third to one-half of the total grate area, and one square foot of passage is usually provided for every 3 to 3.5 square feet of air space of the grate.

Ques. Is the area of the gas passages uniform throughout its course?

Ans. No.

The area of the passages decreases, usually toward the funnel, making the gases travel faster when the heat excess is smaller.

Ques. How should the water space be arranged?

Ans. It should be so designed that the steam evaporated from the heating surface can, by rapid and undisturbed circulation, be replaced by water.

Ques. Why is rapid circulation desirable in boilers?

Ans. It is needed to prevent overheating of the heating surface; since water should be kept in contact with the heating surface in order to absorb sufficient heat to avoid dangerous temperatures.

Ques. What is the steam space?

Ans. That part of the interior of the boiler above the *water line*, in which steam is stored.

The steaming space, if too small, will cause undue fluctuation of pressure on sudden demand, and if too large will present an unreasonably large wall area to the relatively cold exterior, thus causing undue *condensation*.

Ques. What is the liberating surface?

Ans. The water surface or area of contact between water and steam.

It provides for the *liberation* or escape of the steam bubbles from the water, hence its name.

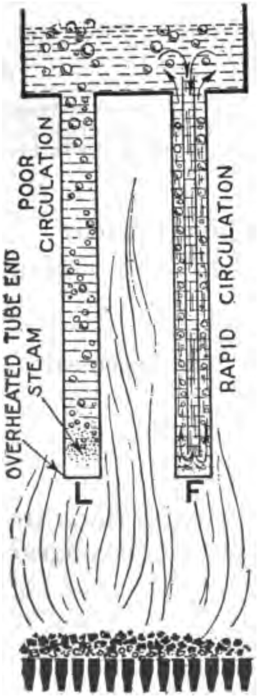
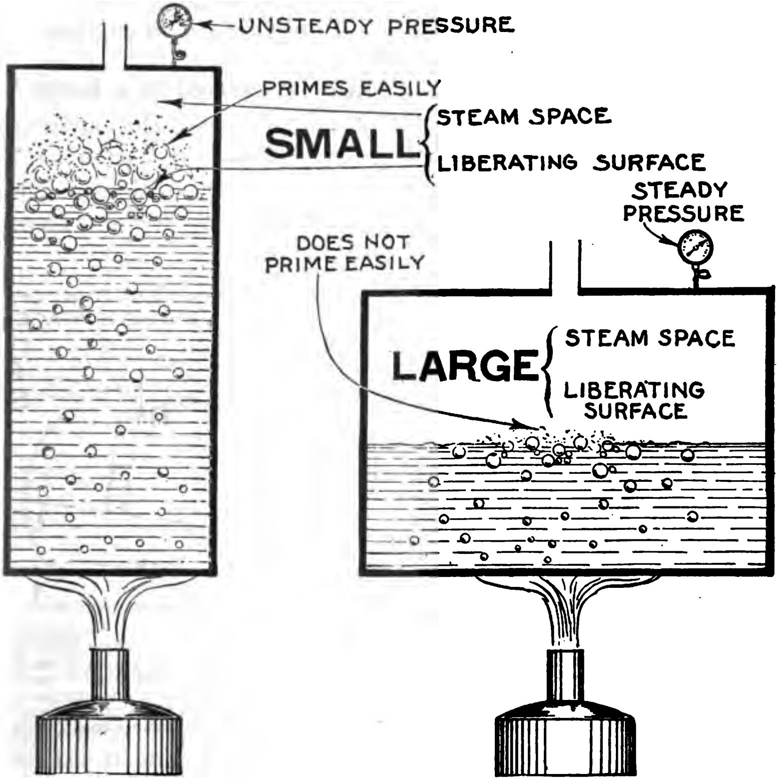


FIG. 3,546.—Importance of rapid circulation. Because of the poor circulation in tube **L**, the excess steam forming at the bottom of the tube tends to drive the water upward, thus the metal is left unprotected and quickly becomes overheated by the intense heat from the furnace. With an inner tube to promote circulation as in tube **F**, there is a constant flow of cool water over the metal with the result that the steam is carried off to the liberating surface as soon as it is formed, thus preventing the metal becoming overheated.

Ques. What is the result of insufficient liberating surface?



FIGS. 3,547 and 3,548.—Influence of the size of steam space and liberating surface. The steam space forms a reservoir for the storage of steam, hence if it be small, as in fig. 3,547, a sudden and large demand for steam will cause a considerable drop of pressure and the accompanying violent ebullition to re-establish equilibrium between pressure and temperature will cause priming, carrying over a large amount of spray into the steam main. The priming effect being increased by the small area of liberating surface for the discharge of steam into the steam space. When the steam space and liberating surface are large as in fig. 3,548, the opposite conditions obtain.

Ans. It causes priming, on account of the great violence with which the steam globules break through the water surface.

Ques. What is priming?

Ans. The carrying of small water particles in dangerous quantities into the steam rendering it unfit for use in engines.

Ques. How much water should be carried in a boiler?

Ans. There should be enough to cover all the heating surface subjected to the intense heat of the fire, at least several inches deep, giving due consideration to inclined positions which boilers other than stationary may assume, as for instance, tractors, locomotive or marine boilers.

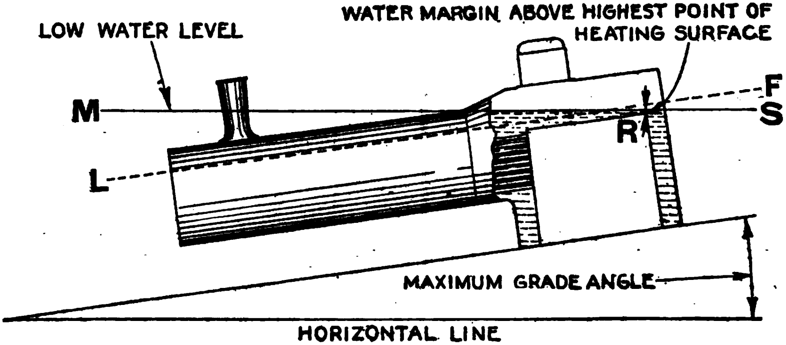


FIG. 3,549.—Diagram illustrating height of water to be carried in a boiler. There must be enough water to cover all the heating surface for any position the boiler may assume in practice. Thus, in the case of a locomotive, if the boiler be tilted to the angle of maximum grade, evidently the water level should be at the level MS, giving a safe margin of water R, above the crown sheet. Now, if the boiler be tilted back to its horizontal position, the water line MS, would assume some position as LF. Hence, the lowest gauge cock should be located on the line LF.

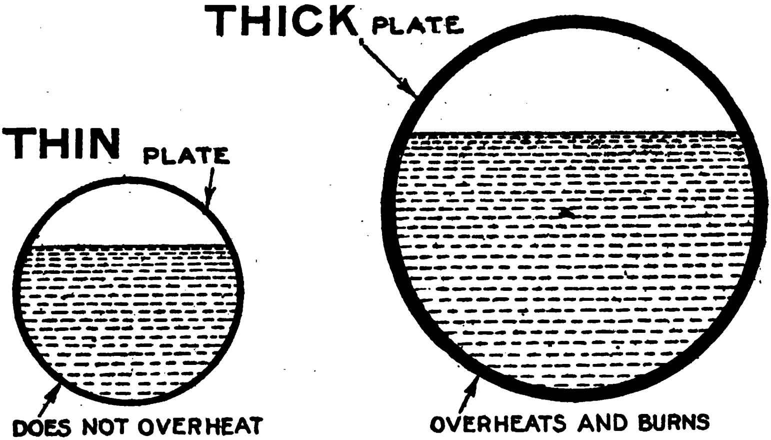
Ques. What auxiliaries may be added to the heating surface to more efficiently absorb the heat?

Ans. Feed water heater, super-heater, and economizer.

Feed water heater heats the feed water before it enters the boiler; a superheater heats the steam to a temperature greater than that due to its pressure and an economizer is a supplementary heating surface interposed between the boiler and chimney to absorb as much of the heat that would otherwise go up the chimney, as is commercially feasible.

Ques. In large plants why are several boilers used instead of one of equivalent capacity?

Ans. 1, for mechanical reasons, especially in the case of shell boilers the size is limited, 2, in case of accident, only part of the boiler plant need be shut down during repair; 3, for variable load, the number of boilers in operation may be altered to suit the demand for steam.



FIGS. 3,550 and 3,551.—One reason why very large shell boilers are not used.

Ques. What is the chief difference in behaviour of water tube and shell boilers?

Ans. A water tube boiler is more sensitive to changes in combustion conditions than a shell boiler.

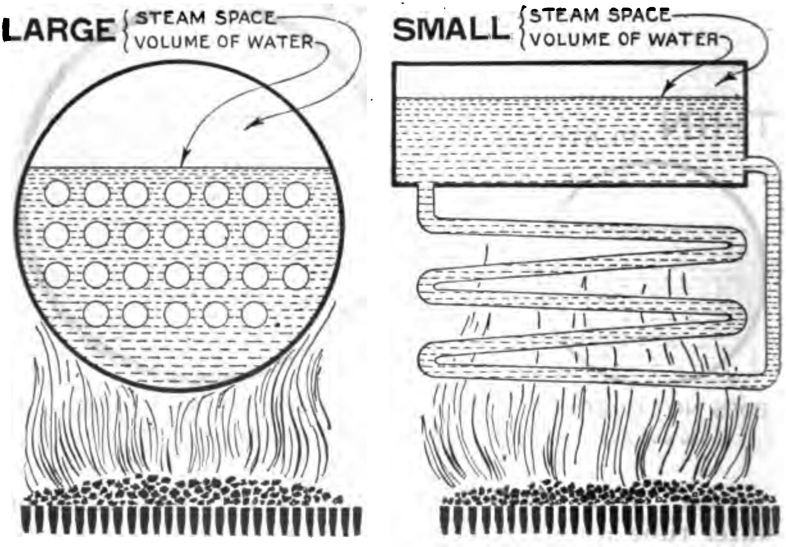
Ques. Why?

Ans. Its response to changes in the rate of combustion is quicker because it carries less water in proportion to the heating surface.

Ques. State some other differences?

Ans. In case of a sudden demand for steam, the pressure will fall more in a water tube boiler than in a shell boiler, because the relatively large volume of water in the shell boiler forms a "reservoir" for the storage of heat.

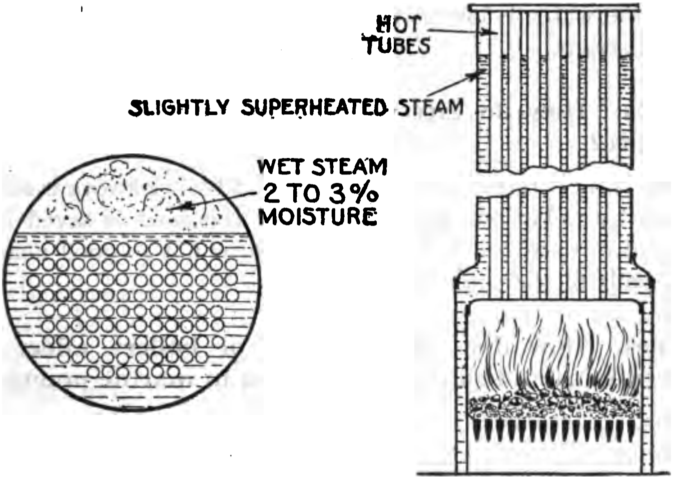
The fluctuations in water level are usually greater in water tube boilers, and because of the relatively small amount of water carried, they require closer attention than shell boilers.



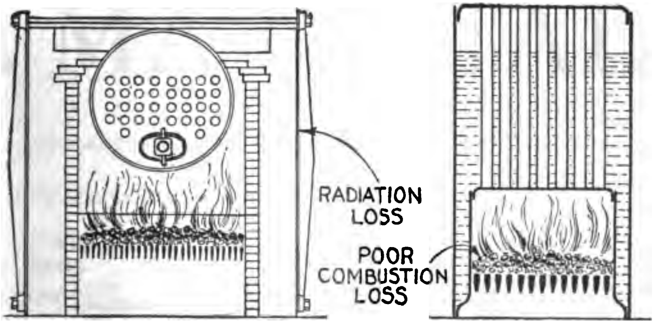
Figs. 3,552 and 3,553.—Sensitiveness of shell and water tube boilers. The shell boiler with its large steam and water spaces is less sensitive to sudden load changes than the water tube boiler.

Ques. What is the difference between the steam generated in a horizontal shell boiler and in a vertical boiler with full length tubes?

Ans. The horizontal boiler usually furnishes steam with 2% or 3% of moisture while the vertical boiler, especially



Figs. 3,554 and 3,555.—Difference between the steam generated in a horizontal and a through tube vertical boiler. Ordinarily a horizontal boiler furnishes steam with 2 to 3 per cent moisture, but in the case of a vertical boiler (especially those of the Manning type) the multiplicity of hot tubes, a part of whose surface is in the steam space, transmits heat to the steam and slightly superheats it.



Figs. 3,556 and 3,557.—Characteristics of external and internal furnaces. An external furnace (fig. 3,556) is subject to loss of heat by radiation, whereas, in an internal furnace (fig. 3,557) there is a loss due to poor combustion of the fuel in contact with the furnace walls.

when the water is low in the glass, will produce slightly superheated steam.

Ques. How do external and internal furnace boilers compare?

Ans. An external furnace surrounded by brickwork is subject to loss by radiation, whereas most of this heat is saved in an internal furnace boiler, but combustion is not so good near the cool walls of the internal furnace.

Ques. How does the position of boilers affect the convenience and safety of handling in marine practice?

Ans. The boilers may be placed low in the hold, as in most sea going ships, or above the water line, as in many river and bay steamers. The latter position affords a certain convenience in discharging ashes and handling coal, while the former is the safer for sea going ships.

In many steamers care must be taken that the heat of the boilers will not prove injurious to the ship or cargo.

CHAPTER 63

BOILER MATERIALS

In the construction of a steam boiler, a very small variety of materials are used, yet the subject of boiler materials is of considerable importance both to the designer and operator; it may be divided into three sections:

1. Materials
2. Properties
3. Tests

These will now be taken up in the order given.

1. MATERIALS

The substances ordinarily used in boiler construction are:

1. For the boiler proper
    - *a.* Copper.
    - *b.* Brass.
    - *c.* Iron $\left\{\begin{array}{l}\text{cast}\\ \text{malleable}\end{array}\right.$
    - *d.* Steel $\left\{\begin{array}{l}\text{various}\\ \text{grades}\end{array}\right.$
2. For the setting or case

a. Brick.
b. Various insulators $\left\{\begin{array}{l}\text{asbestos,}\\ \text{etc.}\end{array}\right.$

In early days copper was used for the furnace sheets and stay bolts in locomotive boilers and brass for tubes, copper being regarded as the ideal material for the purposes mentioned because of some of its properties.

With the gradual increase in steam pressures, copper and cast iron were found to be unreliable and were discarded in favor of wrought iron and steel although copper tubes are stlll employed in special types.

Copper.—The usual method of separating copper from its ore is by means of heat and is known as smelting. In the U. S. the ore is smelted to a *matte* containing 45% or 50% of copper and then reduced to *blister* copper in a converter.

In nearly all cases the copper must be refined, usually electrically, so as to remove those impurities that will not go into the slag, nor be oxidized like sulphur.

If the matte contain less than 40% of copper, the cost of converting will be excessive; if more than 70%, it will be difficult to concentrate the copper.

Coarse ores are treated more rapidly and to better advantage in blast than in reverberatory furnaces; fine ores are best treated in a reverberatory furnace.

Both the blast and reverberatory furnaces are the same in principle as those used in the iron industry.

Brass.—Mixtures of *copper* and *zinc* are called *brass*. Any mixture of two or more metals is known as an alloy. Seamless brass tubes are made from 1/8 inch to 1 inch outside diameter, varying by 1/16 inch, and from 1 1/8 inches to 10 inches outside diameter, varying by 1/8 inch and in all gauges from 2 to 24 *A.W.G.*

Brick.—The best brick clays are composed of $\frac{3}{5}$ silica, $\frac{1}{5}$ alumina, and $\frac{1}{5}$ iron, magnesia, soda, potash and water.

Excess alumina over silica causes the brick to crack in burning. When sand is added to the clay it should be clean, sharp, fusible and not too fine. The materials of fire brick are generally fire clays which are hydrated silicates of alumina, containing from 50% to 65% of silica, 30% to 75% of alumina, and 11% to 15% of water.

Cast Iron.—According to the specifications adopted by the International Association for Testing Materials *cast iron* is defined as *iron containing so much carbon that it is not* **malleable** *at any temperature*. It consists of a mixture and combination of iron and carbon, with other substances in varying proportions.

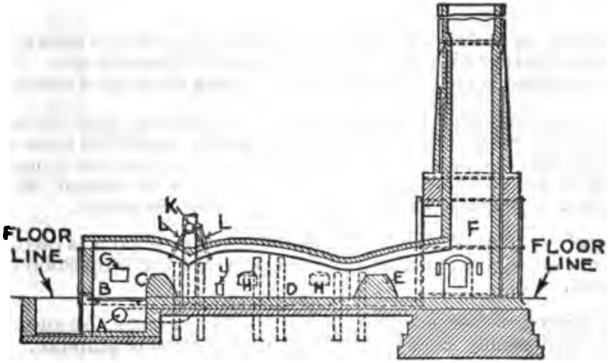


FIG. 3,558.—Air furnace for melting iron to be used for malleable castings. A blast for the pipe A, passes through the fuel bed B, over the bridge wall C, to the metal on the refractory bed D, then over the bridge wall E, into chimney F. The door G, gives access to the fuel bed and the doors H, to the molten iron, which is drawn off through the tap J. Frequently, air pipes are placed in the first bridge wall C, so as to add air to the flames, slightly improving the combustion. In the furnace shown the auxiliary air is furnished by a pipe K, running across the top of the furnace and feeding a number of small pipes L that supply the air near the bridge wall so as to obtain the greatest combustion just over the lapping spout. Sometimes the apping spouts are placed at different levels so that the hottest metal can be drawn off first, thus preventing its burning as well as making the composition of the casting nearer uniform. The heating of the bath is aided by the arched roof, which deflects the heat toward the molten metal. The bath should be deepest by the hedge wall C, and slope upward toward the bridge wall E. To avoid burning the metal here, the metal should be 2 or 3 inches deep instead of having a feather edge; the coming of slag then will prevent excessive oxidation of the metal.

Generally, commercial cast iron has between 3% and 4% of carbon. The carbon may be present as graphite as in *gray* cast iron, or in the form of combined carbon, as in *white* cast iron.

In most cases the carbon is present in both forms. Besides carbon, silica, sulphur, manganese, and phosphorus are nearly always present.

Malleable Iron.—The method of producing malleable iron is to convert the combined carbon of white cast iron into an amorphous uncombined condition, by heating the white cast iron to a temperature somewhere between 1,380° and 2,000° F.

The iron (or castings as sometimes called), is packed in retorts or annealing pots, together with an oxide of iron (usually hematite ore). The oxygen in the ore absorbs the carbon in the iron, giving the latter a steel like nature.

An annealing furnace or oven is used for heating, and the castings are kept red hot for several days or several weeks, depending upon the pieces. In order that the process be successful, the iron must have nearly all the carbon in the combined state, and must be low in sulphur, as the latter substance is found to greatly increase the time necessary.

Usually only good charcoal melted iron low in sulphur is used, though a coke melted iron is quite as suitable, provided the proportion of sulphur be small.

The process is not adapted to very large castings, because they cool slowly, and usually show a considerable proportion of graphite.

Wrought Iron.—By definition, wrought iron is *a slag bearing malleable iron which contains comparatively little carbon*. Nearly all the wrought iron now used is made by the ***puddling process.***

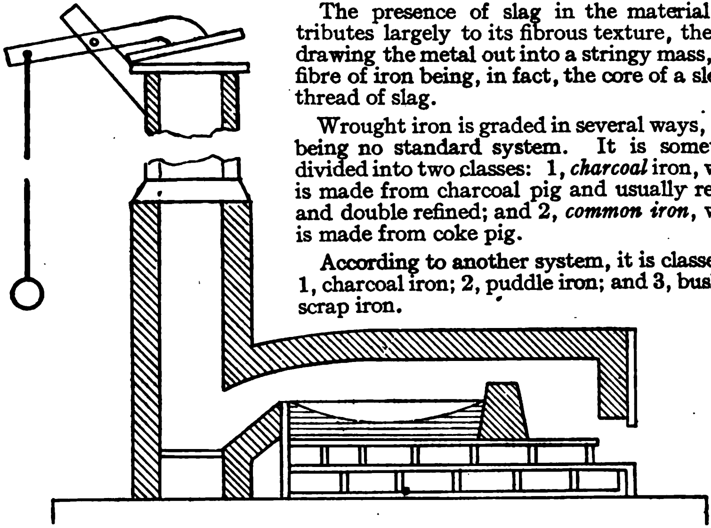
This process leaves the metal in the condition of a soft plastic ball saturated with slag. This ball is taken from the furnace and dropped into a machine which squeezes out most of the slag. It is then passed through a train of rolls which ejects much of the remaining slag and gives the plastic mass the form of a *bar*.

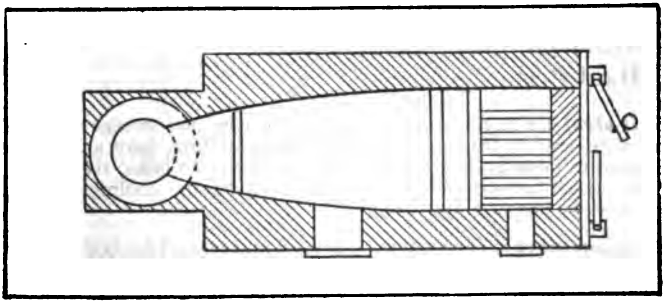
In the making of ***boiler plates,*** the muck bar, as it is called, is cut up into strips; enough strips to produce a sheet of the desired size are bound into a bundle, the bundle is then brought to a welding heat and passed through the rolls. Thus it is that a wrought iron plate consists of a series of welds. This accounts for its laminar structure.

The presence of slag in the material contributes largely to its fibrous texture, the rolls drawing the metal out into a stringy mass, each fibre of iron being, in fact, the core of a slender thread of slag.

Wrought iron is graded in several ways, there being no standard system. It is sometimes divided into two classes: 1, *charcoal* iron, which is made from charcoal pig and usually refined and double refined; and 2, *common iron*, which is made from coke pig.

According to another system, it is classed as: 1, charcoal iron; 2, puddle iron; and 3, busheled scrap iron.





FIGS. 3,559 and 3,560.—Puddling furnace capacity usually from 1,000 to 6,000 pounds of iron. The fireplace is rectangular and is separated from the bath by a low bridge wall. The roof is arched and slopes toward the flue which causes the flames to beat down upon the metal. The air supply is regulated by the damper at the top of the stock, forced draught being used. The bridge work overlaps the tops of the side frames, so as to form a recess for the *fettling* or *fix* with which it is lined. This fettling is a mixture of oxide of iron and sand from the bottom of the hearth. Under the great heat generated in the furnace, some of this sand melts with the pig iron and forms what is called a bath in which the puddling process is carried on. The silica in the sand unites with the iron and makes a slag, which protects the iron from oxidizing so that large sized puddle balls can be made. A large percentage of slag is worked out in the further refining which the metal receives.

Steel.—At the present time, steel is the most important material of construction. Its low price, combined with its great strength, permits its application to the largest and most severely-strained constructive members. It can be forged or cast in any convenient form, and is readily obtained in form of plates, bars, and other shapes.

A disadvantage is that it is rather readily influenced by rust and corrosion, requiring systematic and careful attention in order to preserve it against the action of moisture, oxygen and carbonic acid, and insure its continued usefulness.

It is also attacked by galvanic action, in connection with copper or brass, upon immersion in a polarizing fluid.

In regard to its percentage of carbon, steel occupies a middle position between cast iron and wrought iron. In common with the former, it has a sufficiently low melting point for casting, and, in common with the latter, a sufficient toughness for forging.

According to their varying percentages of carbon, three kinds of steel may be recognized:

1. Soft steel.
2. Medium steel.
3. Hard steel.

Soft steel is nearest to wrought iron in carbon percentage and qualities, being soft, readily forged, and, by careful handling, may also be welded. It is used in principally the flanged parts, furnace plates, rivets and other details, which are exposed to alternate heating and cooling, or to severe treatment by shaping and forming.

Medium steel is harder than soft steel and is used for boiler shells.

Cast Steel has about the same percentage of carbon as soft or medium steel. It has in addition silicon and manganese which are needed to produce good castings.

Hard steel comes the nearest to cast iron in carbon percentage, and possesses, as its most important quality, a decided facility for tempering and hardening upon sudden cooling in water.

With modern methods, steel is produced by reducing the carbon percentage of cast iron to the desired amount. This may take place in two ways by:

1. Bessemer process.
2. Open hearth process.

Bessemer Process.—This process consists in blowing air into a vertical, pear shaped converter, full of molten cast iron. The air is blown in at the bottom, and rising through the molten mass burns the carbon. If the air admission be arrested at the right time a steel of predetermined quality and hardness may be obtained.

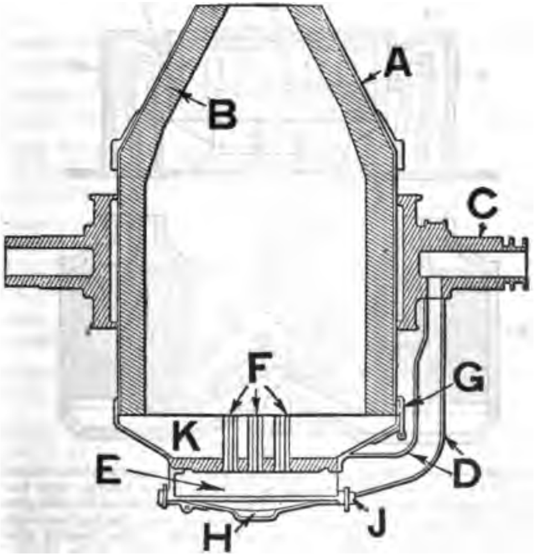


Fig. 3,561.—Bessemer converter. ***It consists of*** a large steel shell A, lined with a refractory material B, and turning on trunnions C. Air entering through one trunnion passes through the pipes D, and the tuyere or wired box E, into the converter through the tuyeres F. A refractory bottom K, is fastened to the shell by the key link G, and the lid H, is fastened to the tuyere box by the key J. As the lining corrodes rapidly around the tuyeres, the bottom is made easily removable for quick replacement with a new one.

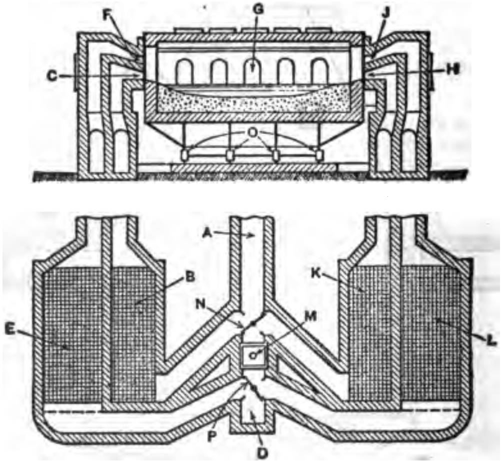
The converter is tripped on trunnions and its contents poured into moulds.

The ingots coming from these moulds are then rolled into plates or shapes, or forged out, as required.

Bessemer steel is objected to by some engineers, as not possessing uniformity of qualities throughout the material obtained from the same converter. Further, it is not always possible to determine the exact point at which to arrest the admission of air, with consequent uncertain results.

Open Hearth Process.—In this method cast iron is deprived of its surplus carbon in a shallow furnace, where the molten material is exposed, on a broad surface, to passing currents of air and gases, which burn out the carbon.

The molten mass can be mixed and stirred, and, by removing a small amount as a sample, can also be tested. By this means the reduction of carbon can be more accurately adjusted to the desired degree. The open hearth product is regarded by many engineers as nearer uniform in qualities, and, therefore, preferable for most purposes.



FIGS. 3,562 and 3,563.—Open hearth furnace and plan of regenerative chambers and flues. Usual capacity 50 to 60 tons. ***It consists of*** a rectangular hearth with parts at each end through which the gas enters and leaves. Two chambers at each end provide means for heating the air and the gas. The roof of the furnace must be high enough so that it will not be burned up by an impinging flame from the parts. The hearth must be of such a length that there will be complete combustion; its length should be about 2 to 2½ times its width; and its depth sufficient to permit oxidation of the metal, yet shallow enough to give thorough heating and reasonably quick working of the bath.

Iron and Steel Definitions.—At the Brussels Congress of the International Association for Testing Materials held in

September, 1906, the following definitions of the most important forms of iron and steel were adopted:

DEFINITIONS

Alloy cast irons.—Irons which owe their properties chiefly to the presence of an element other than carbon.

Alloy steels.—Steels which owe their properties chiefly to the presence of an element other than carbon.

Basic pig iron.—Pig iron containing so little silicon and sulphur that it is suited for easy conversion into steel by the basic open-hearth process (restricted to pig iron containing not more than 1.00 per cent of silicon).

Bessemer pig iron.—Iron which contains so little phosphorus and sulphur that it can be used for conversion into steel by the original or acid Bessemer process (restricted to pig iron containing not more than $\frac{1}{10}$ per cent of phosphorus).

Bessemer steel.—Steel made by the Bessemer process, irrespective of carbon content.

Blister steel.—Steel made by carburizing wrought iron by heating it in contact with carbonaceous matter.

Cast iron.—Iron containing so much carbon or its equivalent that it is not malleable at any temperature. The committee recommends drawing the line between cast iron and steel at 2.2 per cent carbon.

Cast steel.—The same as crucible steel; obsolete, and confusing; the terms "crucible steel" or "tool steel" are to be preferred.

Converted steel.—The same as blister steel.

Charcoal hearth cast iron.—Cast iron which has had its silicon and usually its phosphorus removed in the charcoal hearth, but still contains so much carbon as to be distinctly cast iron.

Crucible steel.—Steel made by the crucible process, irrespective of its carbon content.

Gray pig iron and gray cast iron.—Pig iron and cast iron in the fracture of which the iron itself is nearly or quite concealed by graphite, so that the fracture has the color of graphite.

Malleable castings.—Castings made from iron which when first made is in the condition of cast iron, and is made malleable by subsequent treatment without fusion.

Malleable iron.—The same as wrought iron.

Malleable pig iron.—An American trade name for the pig iron suitable for converting into malleable castings through the process of melting, treating when molten, casting in a brittle state, and then making malleable without remelting.

Open hearth steel.—Steel made by the open-hearth process irrespective of its carbon content.

Pig iron.—Cast iron which has been cast into pigs direct from the blast furnace.

Puddled iron.—Wrought iron made by the puddling process.

Puddled steel.—Steel made by the puddling process, and necessarily slag-bearing.

Refined cast iron.—Cast iron which has had most of its silicon removed in the refinery furnace, but still contains so much carbon as to be distinctly cast iron.

Shear steel.—Steel, usually in the form of bars, made from blister steel by shearing it into short lengths, piling, and welding these by rolling or hammering them at a welding heat. If this process of shearing, etc., be repeated, the product is called "double-shear steel."

Steel.—Iron which is malleable at least in some one range of temperature and, in addition, is either (1), cast into an initially malleable mass; or (2), is capable of hardening greatly by sudden cooling; or (3), is both so cast and so capable of hardening.

Steel castings.—Unforged and unrolled castings made of Bessemer, open-hearth, crucible, or any other steel.

Washed metal.—Cast iron from which most of the silicon and phosphor have been removed by the Bell-Krupp process without removing much of the carbon, still contains enough carbon to be cast iron.

Weld iron.—The same as wrought iron; obsolete and needless.

White pig iron and white cast iron.—Pig iron and cast iron in the fracture of which little or no graphite is visible, so that their fracture is silvery and white.

Wrought iron.—Slag-bearing, malleable iron, which does not harden materially when suddenly cooled.

2. PROPERTIES OF MATERIALS

It is essential that anyone engaged in the design, construction, erection, or operation of a steam boiler should be familiar with the *nature* of the various materials entering into its construction.

A material is said to possess certain *properties* which define its character or behaviour under various conditions.

The following definitions of terms used to express the properties of materials entering into boiler construction should be noted:

DEFINITIONS

Brittle.—Breaking easily and suddenly with a comparatively smooth fracture; ***not*** *tough* or *tenacious*. This property usually increases with *hardness*. The hardest and most highly tempered steel is the most brittle; white iron is more brittle than grey, and chilled iron than any other. The brittleness of castings and malleable work is reduced by annealing.

Cold short.—The name given to the metal when it cannot be worked under the hammer or by rolling, or be bent when cold without cracking at the edges. Such a metal may be worked or bent when at a great heat, but not at any temperature which is lower than about that assigned to dull red.

Cold shut.—In foundry work, when, through cooling, the metal passing round the two sides of a mould does not properly unite at the point of meeting.

Ductile.—Easily drawn out; flexible; pliable. Material, as iron, is "ductile" when it can be extended by pulling.

Elastic limit.—The greatest strain that a substance will endure and still completely spring back when the strain is released.

Fusible.—Capable of being melted or liquefied by the action of heat

Hardness.—The quality or state of being hard in any sense of the word.

Homogeneous.—Of the same kind or nature; hence, homogeneous, as applied to boiler plates, means even grained. In steel plates there are no layers of fibers, and the metal is as strong one way as another.

Hot short.—More or less brittle when heated; as hot short iron.

Melting points of solids.—The temperature at which solids become liquid or gaseous. All metals are liquid, at temperatures more or less elevated, and they probably all turn into gas or vapor at very high temperatures. Their melting points range from 39 degrees below zero of Fahrenheit's scale, the melting, or rather the freezing point of mercury, up to more than 3,000 degrees.

Resilience.—The act or quality of elasticity; the property of springing back or recoiling upon removal of a pressure, as with a spring. Without special qualifications the term is understood to mean the work given out by a spring, or piece, strained similarly to a spring, after being strained to the extreme limit within which it may be strained again and again, without rupture or receiving *permanent set*.

Specific gravity.—The weight of a given substance relatively to an equal *bulk* of some other substance which is taken as a standard of comparison. Water is the standard for liquids and solids, air or hydrogen for gases. If a certain mass be weighed first in air, then in water, and the weight in air divided by the loss of weight in water, the result will give the specific gravity; thus, taking a ten pound piece of cast iron, its weight suspended from the scale pan in a bucket of water, will be 8.6 pounds, dividing 10 by the difference 10—8.6 or 1.4, the answer will be 7.14, which is the specific gravity of cast iron.

Strength.—Power to resist force; solidity or toughness; the quality of bodies by which they may endure the application of force without breaking or yielding.

Tenacity.—The attraction which the molecules of a material have for each other, giving them the power to resist tearing apart. The strength with which any material opposes rupture, or its *tensile strength*.

Tough.—1. Having the quality of flexibility without brittleness; capable of resisting great strain; able to sustain hard usage; not easily separated or cut.

2. Material, as iron, is said to be "tough" when it can be bent first in one direction, then in the other, without fracturing. The greater the angles it bends through (coupled with the number of times it bends), the tougher it is.

Weldable.—A term applied to material; as iron, if it can be united, when hot, by hammering or pressing together the heated parts. The nearer the properties of the material, after being welded, are to what they were before being heated and welded, the more *weldable* it is.

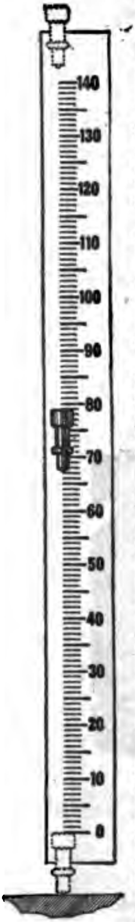


FIG. 3,564.—Principle of the *scleroscope* or instrument for determining the hardness of metal. ***Briefly***, the essential part of the scleroscope is a hard steel hammer with a properly formed diamond at its striking end, which is allowed to drop upon the surface of the metal under test. After striking and indenting the metal, the hammer rebounds, and in amount proportional to the hardness of the metal, which is read direct on the scale. The figure shows the hammer in dotted lines at the point from which it drops and where it strikes the metal, and in perspective at the point to which, in this case, it has rebounded. ***The scale.*** The hardness of quenched carbon steel was accepted as 100. But no metal comes down to zero in hardness (which is as it should be, for zero is no measure at all); but pure lead, for instance, is 2 hard. Thus the hardness of quenched carbon steel is established as unity, and the hardness of other metals may, if desired, be expressed in percentage figures. On that basis, lead is 2 per cent hard, and martensite high-carbon steel may be as high as 110 per cent hard.

In addition to these definitions, others will be found, being terms used in testing and representing the behaviour of material under tests.

Copper.—The strength of copper decreases rapidly with rise of temperature above 400° F.; between 800° and 900° its strength is reduced about half that at ordinary temperatures. Copper is not easily welded, but may be readily braised. At near the melting point it oxidizes or is *burned* as it is called and loses most of its strength, becoming brittle when cool.

Brass.—When zinc is present in small percentages the color of brass is nearly red; ordinary brass for piping, etc., contains from 30% to 40% of zinc. Brass can be readily cast, rolled into sheets, or drawn into tubes, rods and wire of small diameter.

The composition of brass is determined approximately by its color: Red contains 5% of zinc; bronze color, 10%; light orange, 15%; greenish yellow, 20%; yellow, 30%; yellowish white, 60%. The so called low brasses contain 37 to 45% of zinc and are suitable for hot rolling, and the *high* brasses contain from 30 to 40% of zinc, being suitable for cold rolling.

Cast Iron.—The properties of cast iron depend chiefly on the proportion of total carbon, and in the relative proportion of combined carbon and graphite.

Soft cast iron called *gray* iron contains a high percentage of graphite which renders it tough, with low tensile strength; it breaks with a coarse grained dark or grayish fracture.

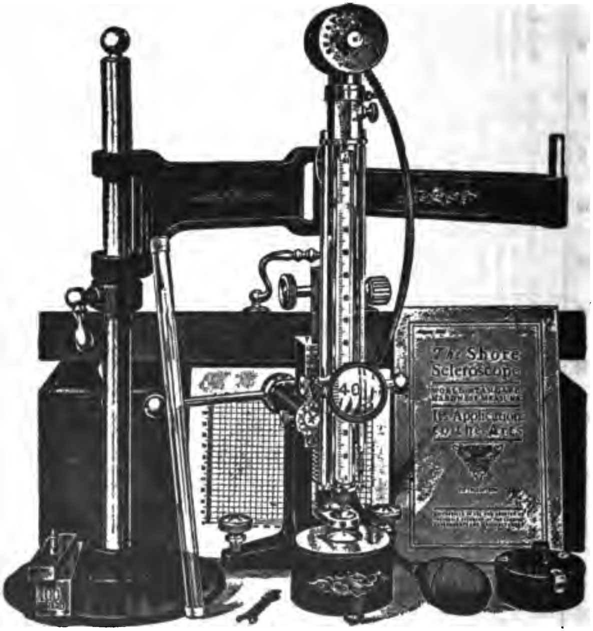


FIG. 3,565.—Shore scleroscope outfit ***consisting of*** scleroscope (self-contained); **plaste mount vessel; swing arm and post; magnifier hammer (for soft metals only); soft and hard steel replace bars; fifty blank curved charts; carrying case.**

NOTE.—The Brinell method of testing hardness consists in pressing a hardened steel ball into the smooth surface of the metal so as to make an indentation which is then measured by *optical* or *mechanical* means to ascertain the hardness of the material. The Brinell test may be applied to unfinished material as well as to manufactured goods, such as rails, structural material, etc.; it will also determine the effects of annealing and hardening of steel and serve as a basis for calculating the tensile strength directly from the results of the hardness test.

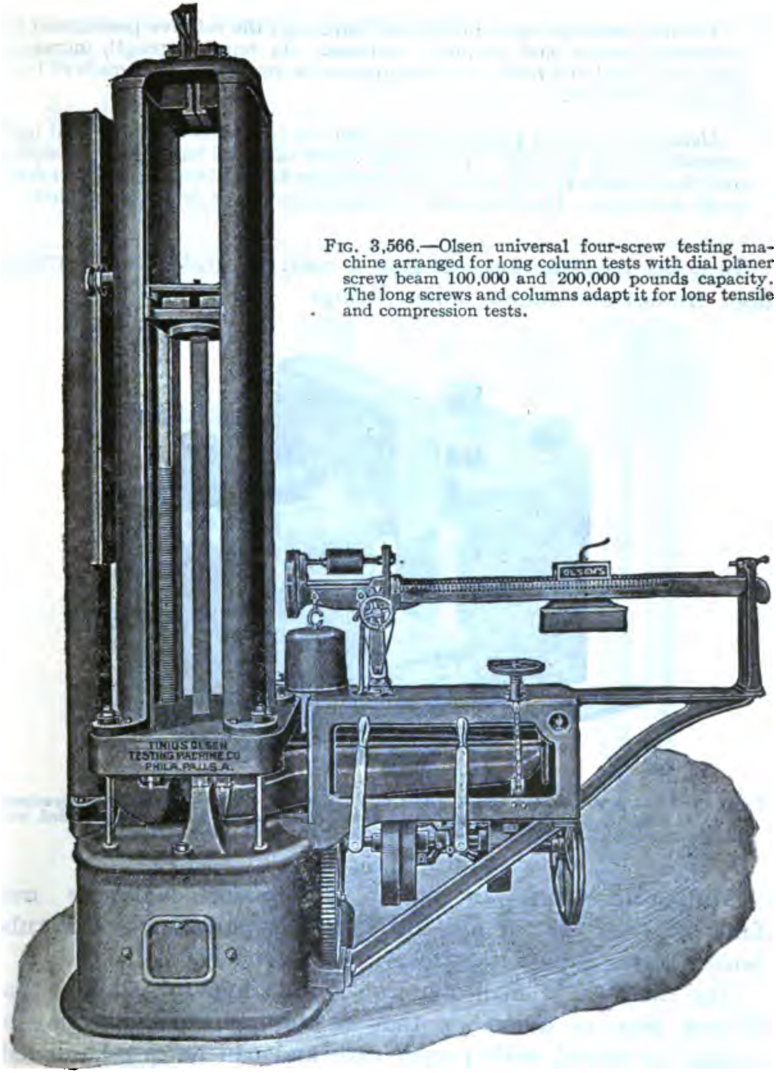
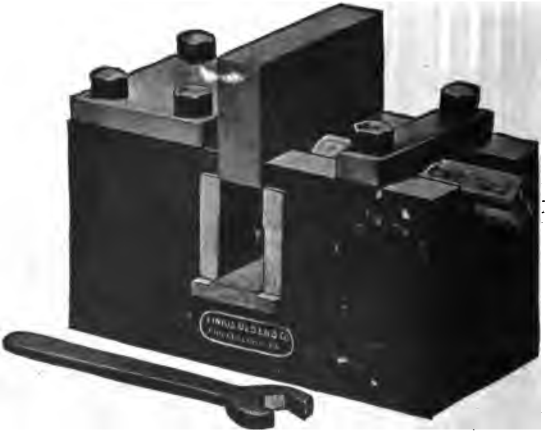


FIG. 3,566.—Olsen universal four-screw testing machine arranged for long column tests with dial planer screw beam 100,000 and 200,000 pounds capacity. The long screws and columns adapt it for long tensile and compression tests.

The iron becomes more brittle and harder as the relative percentage of combined carbon and graphite decreases; its tensile strength increases somewhat, and the fracture is fine grained or smooth. This grade of iron is called *white* iron.

Mottled iron is that grade in which half the carbon is combined and half separates out as graphite. In casting, when cast iron hardens, it expands, and then contracts as it cools, the shrinkage being about ⅛ inch per foot in all directions. Hardness and shrinkage increase or decrease together.

In boiler construction cast iron is used for grate bars, furnace door frames and minor boiler fittings



Figs. 3,567 and 3,568.—Olsen shearing test tool designed for testing 1 inch round specimen in either single or double shear, and at the same block can, if desired, be provided with other shearing tools for testing other sizes of specimen. Fig. 3,568, wrench.

Malleable Iron.—In boiler construction malleable iron finds its chief use for pipe fittings as employed in water tube boilers of the pipe variety.

The ductility of malleable iron is from four to six times that of cast iron, or about $\frac{1}{10}$ that of wrought iron. It may be welded or forged with proper care and can be case hardened.

Good malleable iron will stand considerable bending and twisting before breaking.

Steel.—By mixing with steel certain other metals, mainly manganese, nickel, aluminum, chromium and tungsten, its strength, hardness or toughness may be increased as desired.

The first essential of boiler plate is a uniform blending of the physical properties that will enable the material to recover from the strains induced by the various stresses of operation.

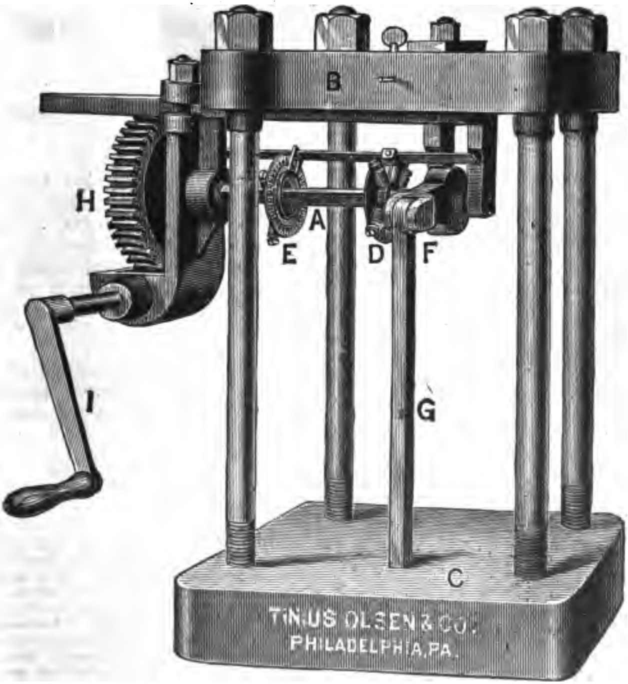


FIG. 3,569.—Olsen *tortion* testing attachment for universal testing machines. The apparatus is bolted to the lower cross head B, and the torque weighed on testing machine table C. The specimen is placed at A, and the tortion applied by hand crank I, through worm drive H, and angular distortion measured from the graduated heads as shown.

The most important of these properties is tenacity, or ability to resist a pulling stress.

Carbon possesses no great strength on its own account, but when joined in chemical affinity with iron it develops strength therein. Correct proportions must be maintained, however. Increasing the carbon content up to a certain per cent. conduces to strength; beyond this point the strength deteriorates.

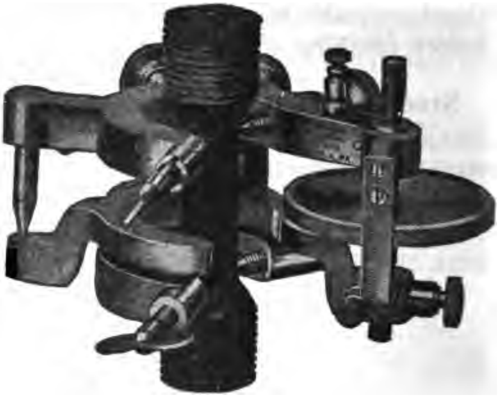


FIG. 3,571.—Olsen micrometer extensometer.

Mild steel that contains. 1 per cent. of carbon, for example, has a tensile strength of about 50,000 pounds per square inch, while 12 times this quantity, or 1.2 per cent, increases the tenacity to nearly 140,000 pounds per square inch, which is probably the limit for carbon steel.

Increasing the percentage of carbon above this figure causes a proportionate drop in the tenacity of the steel.

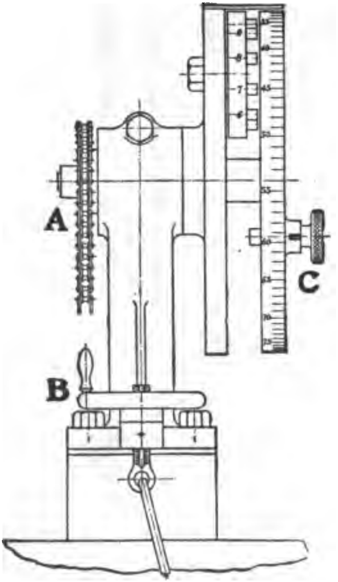


FIG. 3,570.—Malysheff method and attachment for determining elastic limit as used with Olsen universal testing machines. It is adapted to determination of elastic limit where threaded or headed specimens are used and the slip or give in the grips eliminated. ***In testing,*** the reading of the dial is taken for equal increments of load and noted and the difference between successive readings then plotted on small cross section paper and cross plotted for which the elastic limit is noted. The attachment is thrown in and out of operation by means of hand wheel shown at B.

With 2 per cent, its strength is about 90,000 pounds.

A further gradual increase of the carbon component causes the material to rapidly acquire the characteristics of cast iron.

Phosphorus enhances the strength of steel. It also adds to the hardness of the plate and thus makes it better able to resist abrasion. These qualities are, however, best secured through the medium of carbon, because phosphorus tends to make the material brittle. Steel containing much

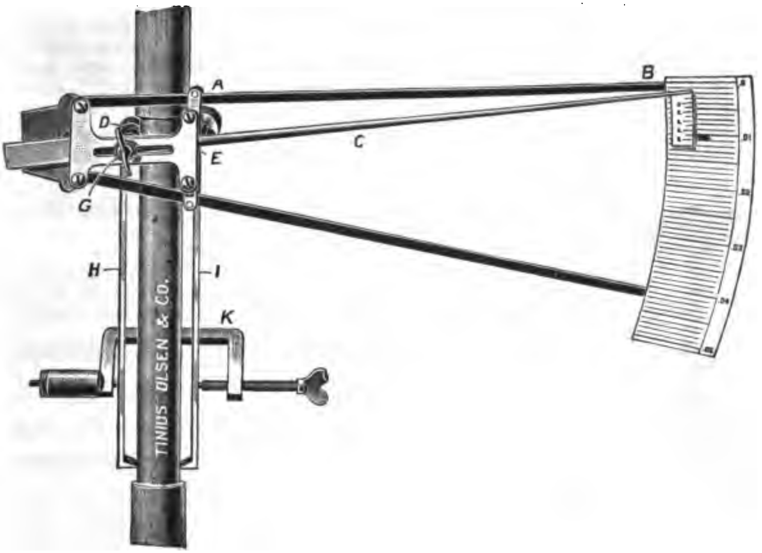


FIG. 3,572.—Olsen extensometer for tension and compression applicable to all sizes and forms of specimens within its maximum range 1⅛ inches round, square or flat specimens. It forms a ready means of observing elastic limit and yield point when correct determinations are required. ***In adjusting*** this instrument, the two points D, E, are separated just to straddle the specimen, and indicator finger C, secured by thumb screw G. In placing instrument on specimen, bar A, B, is placed horizontal as near as may be observed; indicator finger C, to point to upper part of dial, as shown in illustration. The spacing bars H, I, by the clamp K, are placed against the instrument's main pivots D, E, and the specimen, and thus holding the instrument in position. Thumb screw G, is here removed and instrument ready for the test. As shown in cut, instrument is set for compression test readings, and for tension or extension readings spacing bars should point up instead of down, as shown in cut. The instrument is furnished with four verniers, which are marked, the vernier having the mark corresponding to the size of the specimen to be used. Spacing bars for 8-inch length of specimen are furnished, if required, 2-inch, 4-inch, 6-inch, or any other length of spacing bars can be supplied. With the clamp K, the instrument is adjusted to zero when in position after removing the thumb screw G.

phosphorus is particularly weak against shocks and vibratory strains. On this account it may be considered the most harmful impurity in steel boiler plate.

Sulphur increases the brittleness of steel while hot, making it "red short," and interfering seriously with the shaping and forging of the material. It should not exceed from .02 to .05 of one per cent.

Manganese increases the strength, hardness and soundness of the steel. Steel containing a considerable proportion of this element acquires a peculiar brittleness and hardness that makes it difficult to cut. Manganese has, however, a neutralizing effect on sulphur.

Nickel increases both the strength and toughness of the steel.

Aluminum acts upon steel largely in the direction of improving the soundness of ingots and castings.

The standard rules of boiler design require the physical and chemical properties of the grades of steel used for plates, stays and rivets to conform to certain uniform specifications, as later given in detail. The percentage of manganese is left to the discretion of the steel maker.

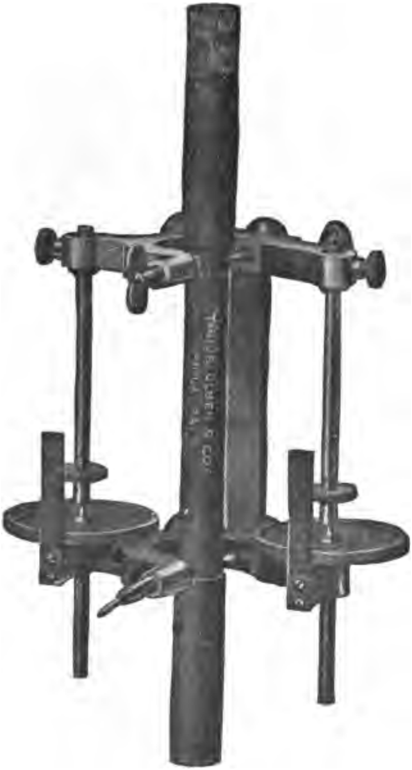


FIG. 3,578.—Olsen duplex micrometer extensometer for round specimens only up to 1½ inches in diameter, and with proper spacing bars and contact point for gauge lengths of form 2 to 8 inches. The instrument is graduated to read .0001 to .00001 of an inch for a length of over 2 inches.

The small quantity of silicon present in boiler plate tends to make the steel slightly harder than it would otherwise be, but apparently without diminishing its roughness or ductility, and also without appreciably affecting its tensile strength.

Brick.—Clay bricks expand or shrink, depending upon the proportion of silica to alumina contained in the brick, but most fire clay brick contain alumina sufficient to show some shrinkage. A straight 9-inch fire brick weighs 7 pounds, a silica brick 6.2 pounds; a magnesia brick, 9 pounds; a chrome brick, 10 pounds. A silica brick expands about 1/8 inch per foot when heated to 2,500° F.

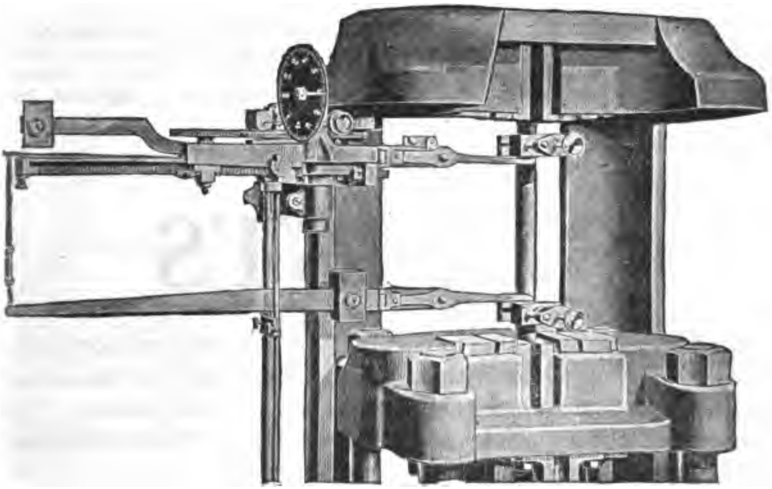


FIG. 3,574.—Olsen extension and compression micrometer. The upper part, or micrometer proper, remains in the same position, as shown, both for extension and compression tests, and also whatever length of specimen is operated upon. The lower part, or arm, is adjusted to the length or kind of test, tensile or compression, that is operated upon. The instrument is operated on the same principle as an extension micrometer with electric contact, only that no double reading is necessary as this instrument itself gives the mean reading. The readings are to .0001 part of an inch. The instrument, or any part of it, cannot be injured by breakage of a specimen, and, as it is carried on supports secured to the machine, it may be left on the machine even if it be not in use, and the machine only used for a test for which it is not required. It is especially adapted for Olsen four-screw machine, on which it occupies a place not otherwise used or utilized.

The melting point of the various kinds of brick ranges from 2,800° to 3,900°F. The chief disadvantage of silicon bricks are brittleness and liability to "spall" when exposed to sudden changes of temperature.

Compressive strength of ordinary fire brick is from 600 to 1,000 pounds per square inch cold, but some of the best range up to 3,000 pounds cold.

Boiler Coverings or Insulators.—According to Kent asbestos is one of the poorest insulators. It may be used to advantage to hold together other incombustible substances, but the less of it, the better.

Any covering should be not less than one inch thick. A covering should be kept perfectly dry, because still water conducts heat about eight times quicker than still air. Some good coverings arranged in order of efficiency (the most efficient first), are: Rock wool, mineral wool, magnesia, hair felt, fire felt.

3. TESTS

In boiler design, the importance of properly proportioning the various parts to withstand the stress due to the steam pressure can not be over emphasized, for obvious reasons. The strength of the materials used in construction is best determined by tests.

Metals are tested for strength in various ways as by taking a sample of standard shape and subjecting it in testing machines to tension, compression, bending, sheering stresses. There are various terms used in testing and the definitions, as here given should be carefully noted.

DEFINITIONS

Bending stress.—In physics, a force acting upon some member of a structure tending to deform it by bending or flexure; the effect of this force causes bending *strain* on the fibers or molecules of the material of which the part is composed. An instance of pure bending stress is given by pulling on the end of a lever, which tends to deflect it while performing work.

Compression.—To press or push the particles of a member closer together, as, for instance, the action of the steam pressure in a boiler on the fire tubes.

Deformation.—Change of shape; disfigurement, as the *elongation* of a test piece under tension test.

Factor of safety.—The ratio between the *breaking load* and what is selected as the *safe working load.* Thus, if the breaking load of a bolt be 60,000 *pounds per square inch,* and the working load be 6,000 *pounds per square inch,* then the factor of safety is 60,000 ÷ 6,000 = 10.

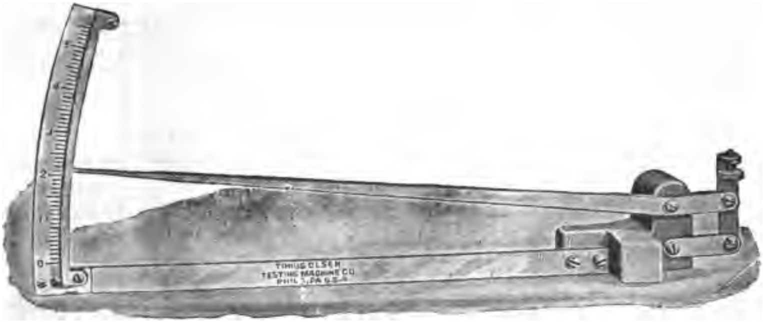


FIG. 3,575.—Olsen deflection instrument for showing the deflection of transverse specimens. Deflection magnified ten times.

Force.—That which changes or tends to change the state of a body at rest, or which modifies or tends to modify the course of a body in motion, as a *pull* pressure or a *push;* a force always implies the existence of a simultaneous equal and opposite force called the *reaction.*

Load.—The total pressure acting on a surface; thus, if an engine piston having an area of 200 square inches be subjected to a steam pressure of 150 pounds *per square inch,* then the load, or total pressure on the piston is 200 × 150 = 30,000 pounds.

Member.—A part of a structure as a brace, rivet, tube, etc., subject to stresses.

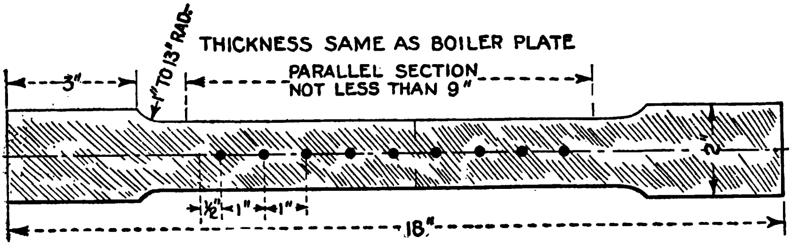

THICKNESS SAME AS BOILER PLATE
1" TO 13" RAD.
3"
PARALLEL SECTION NOT LESS THAN 9"
2"
½"
1"
1"
18"

FIG. 3,576.—*A. S. M. E.* standard specimen required for all tension tests of ***plate material.*** Tension and bend test specimens shall be taken from the finished rolled material. They shall be of the full thickness of material as rolled, and shall be machined to the form and dimensions here shown, except that bend test specimens may be machined with both edges parallel. One tension, one cold bend, and one quench bend test shall be made from each plate as rolled. If any test specimen show defective machining or develop flaws, it may be discarded and another specimen substituted. If the percentage of elongation of any tension test specimen be less than specified in Pars. 28 and 29 below, and any part of the fracture be outside the middle third of the gauged length, as indicated by the scribe scratches marked on the specimen before testing, a retest shall be allowed. The thickness of each plate shall not vary more than .01 inch.

A. S. M. E.—III PHYSICAL PROPERTIES AND TESTS

28 *Tension Tests. a* The material shall conform to the following requirements as to tensile properties:

	FLANGE	FIREBOX
Tensile strength, lb. per sq. in.	55,000—65,000	55,000—63,000
Yield point, min., lb. per sq. in.	.5 tens. str.	.5 tens. str.
Elongation in 8-in., min., per cent (See Par. 29)	$\frac{1,500,000}{\text{Tens. str.}}$	$\frac{1,500,000}{\text{Tens. str.}}$

b If desired steel of lower tensile strength than the above may be used in an entire boiler, or part thereof, the desired tensile limits to be specified, having a range of 10,000 lb. per sq. in. for flange or 8,000 lb. per sq. in. for firebox, the steel to conform in all respects to the other corresponding requirements herein specified, and to be stamped with the minimum tensile strength of the stipulated range.

c The yield point shall be determined by the drop of the beam of the testing machine.

29 *Modifications in Elongation. a* For material over ¾ in. in thickness, a deduction of .5 from the percentages of elongation specified in Par. 28*a*, shall be made for each increase of ⅛ in. in thickness above ¾ in., to a minimum of 20 per cent.

b For material ¼ in. or under in thickness, the elongation shall be measured on a gauge length of 24 times the thickness of the specimen.

30 *Bend Tests. a Cold-bend Tests*—The test specimen shall bend cold through 180 deg. without cracking on the outside of the bent portion; as follows: For material 1 in. or under in thickness, flat on itself; and for material 1 in. in thickness, around a pin the diameter of which is equal to the thickness of the specimen.

A. S. M. E.—MINIMUM THICKNESS OF PLATES AND TUBES

17 *Thickness of Plates.* The minimum thickness of any boiler plate under pressure shall be ¼ in.

18 The minimum thicknesses of shell plates, and dome plates after flanging, shall be as follows:

WHEN THE DIAMETER OF SHELL IS

36 in. or under	Over 36 in. to 54 in.	Over 54 in. to 72 in.	Over 72 in.
¼ in.	5/16 in.	⅜ in.	½ in.

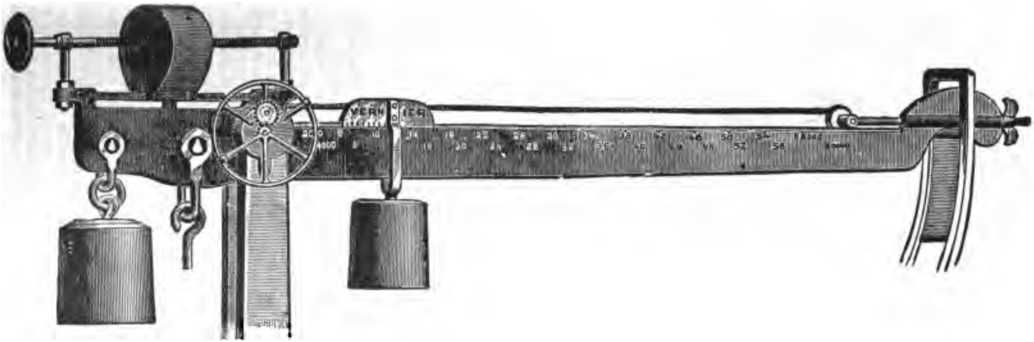


FIG. 3,577.—Riehle weighing beam for testing machines with vernier poise. The poise consists of a traveling weight operated by a hand wheel which operates through gearing; the pitch line of the gears is on the point of pivot, or *point of no vibration* of the beam. When the wheel is turned it does not therefore disturb the equilibrium of the beam. The upper shaft carries a small sprocket which propels the poise by means of a chain. There is a tightener and pulley at the other end for adjustment. The beam is graduated in 100 pound marks and the poise arranged as a vernier to read to 10 pounds in the usual way.

***Modulus* (*or Coefficient*) *of elasticity*.**—The load per unit of section divided by the elongation or contraction per unit of length. Within the elastic limit; when the deformations are proportional to the stresses, the modulus of elasticity is constant, but beyond the elastic limit it decreases rapidly. In wrought iron and steel there is a well defined elastic limit, and the modulus within that limit is nearly constant.

***Modulus of Rupture*.**—A value obtained by experiment upon a rectangular bar supported at the ends and loaded at the middle, substituting results in the formula

$$R = \frac{3\,Pl}{2\,bd^2}$$

in which P = breaking load in pounds; l, b, and d, = length, breadth and depth respectively in inches.

***Permanent set*.**—When a metallic piece is stressed beyond its elastic limit, deformation occurs, the piece being either stretched, crushed, bent or twisted, according to the nature of the strain. This alteration in form is known as *permanent set*.

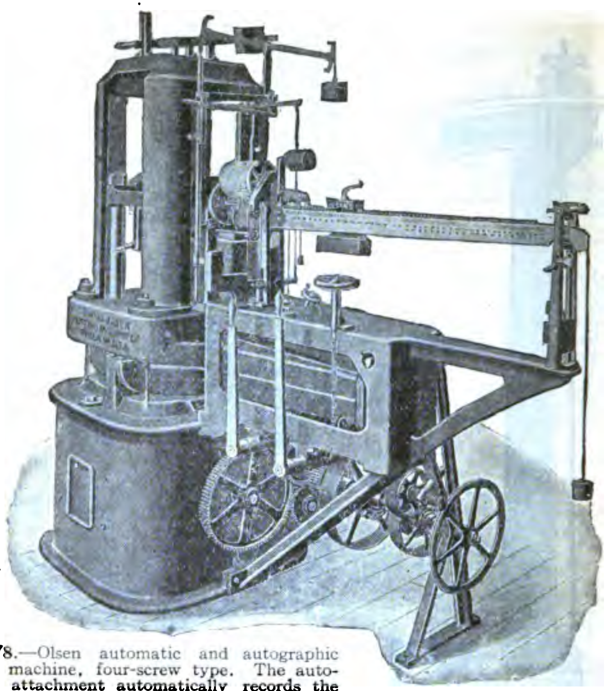


FIG. 3,578.—Olsen automatic and autographic testing machine, four-screw type. The autographic attachment automatically records the characteristics of the test and produces the stress strain diagram. An autographic record may be taken of either a tensile compression or transverse test at any point in the travel of the moving crosshead. The autographic apparatus is mounted on the frame of the machine and is in no way supported by the weighing columns or other parts of the weighing system, thus obtaining the greatest accuracy and sensitiveness. The screw on the scale beam drives both the weighing poise and the recording pencil, so that the reading of the load thus recorded must be correct and correspond to the load weighed. The pencil is arranged with a dotted motion, thus relieving all the friction from the revolving diagram drum, and the dotting is such as to produce an even, continuous line as a record of the test. A variable speed cone system is provided, so that the rate of automatic travel of the weighing poise may be varied quickly to meet conditions of the test and during the test, so as to produce a regular curve at all times. The autographic apparatus may be left in contact with the specimen up to the point of rupture without injury to the apparatus, and thus the curve for the entire test obtained. Special aluminum clamps, which partly take up for the reduction in area of the specimen and a special setting apparatus are provided. ***In operation*** the pencil scribes the movement of the poise on cross section paper which is placed on the revolving drum, the motion of which magnifies the elongation or compression of a specimen ten times. To produce the automatic motion of this recording device, two electric circuits are required; one for operating the poise on the beam and the other for operating the pencil on the diagram drum The scale beam, in rising or falling, makes an electric contact at the top or bottom of the gate in the front beam stand. This contact produces an electric current which excites a series of magnets at the back of the scale beam, which in turn, through a friction gear, operates the screw of the beam, so as to move the poise to balance the beam.

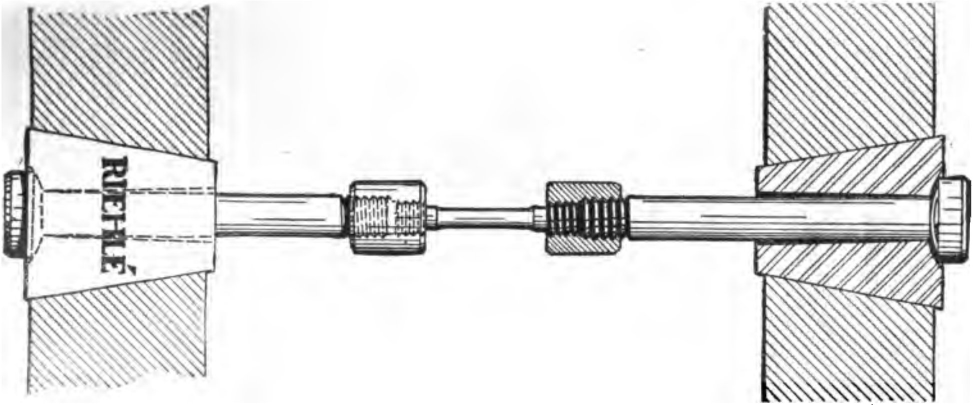


FIG. 3,579.—Riehle self-centering specimen holders. *They consist of* cast iron blocks which fit the heads of the machine, bolts with ball heads threaded on the ends, and the nuts in which the specimen is held. Taper holes are bored in the blocks to allow free motion of the bolts, and sockets are turned in the large end of the blocks in which the ball heads of the bolts rest. The nuts which hold the specimen are screwed on the bolts and the specimen is screwed in these nuts. Nuts for several sizes of specimens can be kept on hand and one set of nuts removed from the bolts and another set put on them. Nuts that hold the specimen are arranged for the specimen adopted by the American Section of International Association for Testing Materials as the Standard American Specimen. This specimen is ½ in. (12.7 *mm.*) diameter with ¾ in. (19.05 *mm.*) U. S. Standard Threaded Ends.

Resilience.—The property of springing back or recoiling upon removal of a pressure, as with a spring. Without special qualifications the term is understood to mean the work given out by a spring, or piece, strained similarly to a spring, after being strained to the extreme limit within which it may be strained again and again, without rupture or receiving *permanent set.*

Shear.—The effect of external forces acting so as to cause adjacent sections of a member to slip past each other. When so acted upon the member is said to be *in shear*.

Strain.—According to *Wood* it is a name given to the kind of alteration produced by the *stresses*. The distinction between stress and strain is not always observed, there being much confusion among writers as to these terms.

Stress.—1. An internal action or *internal force* set up between the adjacent molecules of a body when acted upon by forces. 2. The force, or combination of forces, which produces a strain.

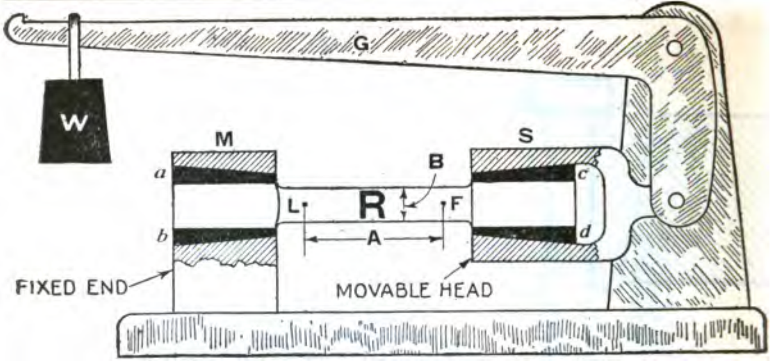
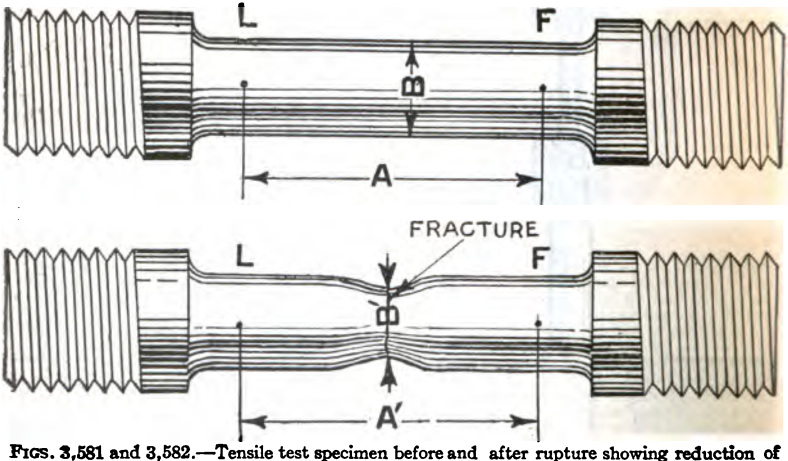


FIG. 3,580.—***Tensile test.*** The specimen R, is placed in the wedge grips *a, b, c, d,* thus pulling it in tension between the fixed end and movable head of the machine. The latter is connected with the scale lever G, upon which slides the weight W, similar to an ordinary weighing scale. Two center marks L and F, are punched on the specimen at a standard distance A, apart. ***In testing,*** the pull on the specimen is gradually increased by moving W, to the left and the dimensions A, and B, measured for each increase of load.



FIGS. 3,581 and 3,582.—Tensile test specimen before and after rupture showing reduction of section B', at break. ***Example,*** Assume A = 2 inches; B = .505 inches then cross area of specimen before test = .2 square inch; this value is used in calculating elastic limit and ultimate strength. Now if the loads be 6,250 and 12,160 pounds, then 6,250 ÷ .2 = 31,250 pounds elastic limit per square inch, and 12,160 ÷ .2 = 60,800 pounds ultimate strength per square inch. To calculate the percentage of elongation, the broken parts are placed together and A' measured. Assuming A' = 2.55 inches, then 2.55 − 2 = .55 in total elongation, and 55 ÷ 2 × 100 = 27½ per cent elongation. Again using micrometer, assume B' to measure .346 inch, then area = .094 inch, and .2 − .094 = .106 square inch total reduction of area from which .106 ÷ .2 × 100 = 53 per cent reduction of area.

Tensile strength.—The cohesive power by which a material resists an attempt to pull it apart in the direction of its fibers, this bears no relation to its capacity to resist compression.

Tension.—The stress or force by which a member is pulled; when thus pulled, the member is said to be ***in tension.***

Ultimate strength.—The maximum unit stress developed at any time before rupture.

Yield point.—The point at which the stresses and the strains become equal, so that deformation or ***permanent set*** occurs. The point at which the stresses equal the elasticity of a test piece.

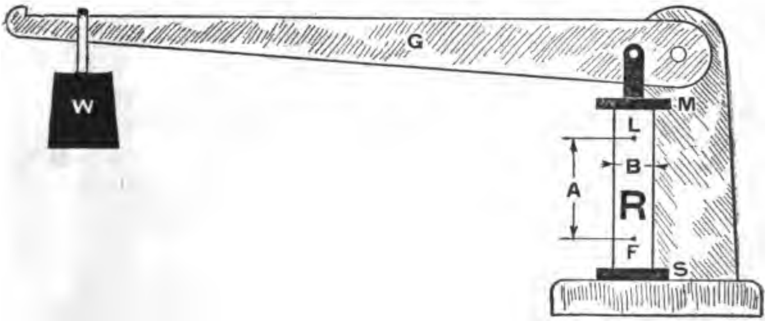


FIG. 3,583.—***Compression test.*** The specimen R, is placed between the two plates M, and S, and a compression stress of any intensity applied by moving the weight W, on the lever G. ***In testing,*** as the load is gradually increased, the changes in dimensions A, and B, are noted and result calculated in a manner similar to that explained for the tension test fig. 3,580.

The materials used in the construction of boilers must pass certain tests, samples or "*specimens*" of the materials having standard forms being taken for the purpose. The various tests that should be made are:

1. Tensile.
2. Compression.
3. Transverse.
4. Shearing.
5. Tortional
6. Hardness.
7. Cold bending.
8. Homogeneity.

These tests are made as here briefly explained, suitable machines being employed in subjecting the specimens to the necessary stresses.

Tension Test.—The specimen is placed in the machine and gripped at each end, then a tension stress is applied gradually increasing in intensity until rupture, noting its elongation, contraction of area for various loads, elastic limit, and breaking load, the results being tabulated thus:

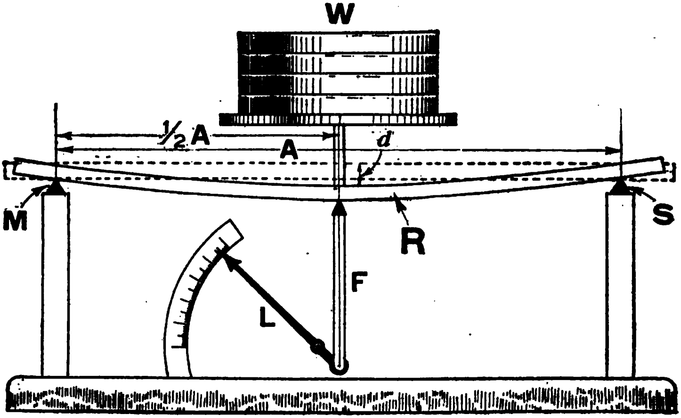


FIG. 3,584.—***Traverse test.*** The specimen R, is placed on two supports M, and S, and a load W, applied at the mid point as shown. The deflection or amount of bending for any load is indicated with precision by the multiplying gear LF. ***In testing,*** the weight W, is gradually increased and deflections noted till the breaking load is reached.

Tensile Test

Specimen: length....inches; cross section....inches; shape........

Load		Contraction of area in %	Elastic limit	Tensile strength
Total in pounds	Pounds per sq. in.			

Fig. 3,580 illustrates the principles of the test and fig. 3,585 the machine employed.

Compression Test.—In making this test the specimen is placed between two plates as in fig. 3,583 and a compression stress applied gradually increasing in intensity until rupture, noting its increase of section, decrease in length, elastic limit for various loads, and its compression strength or load at rupture, the results

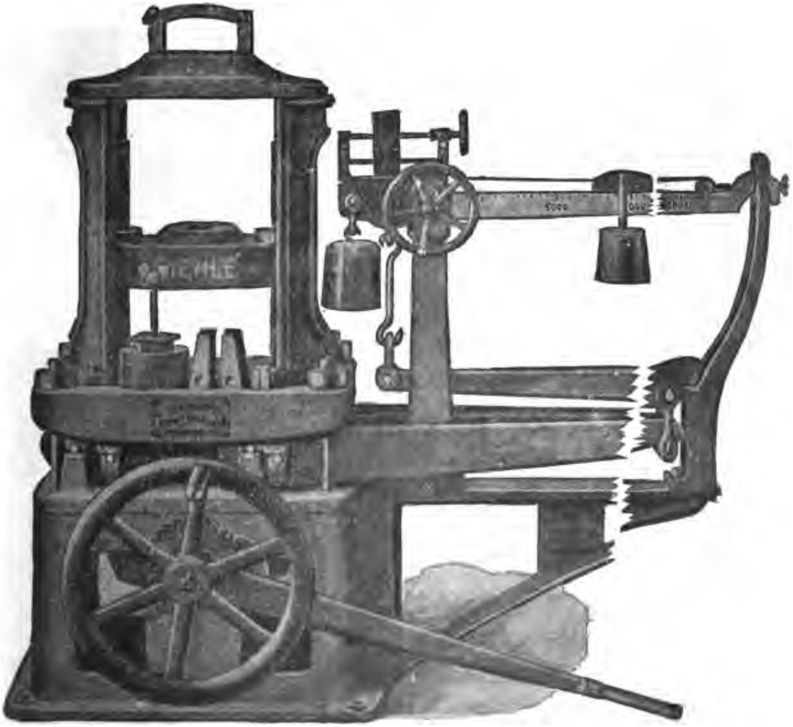
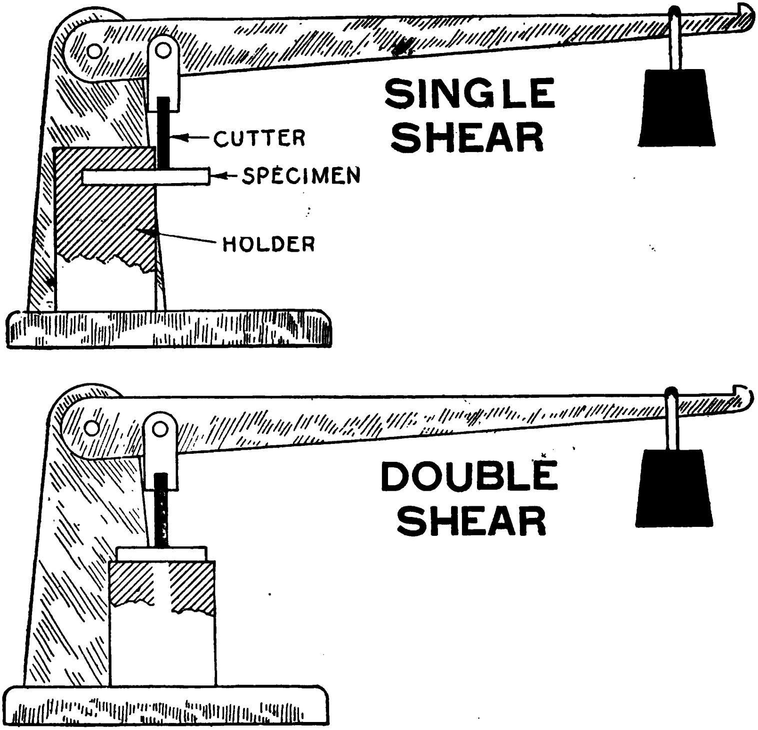


FIG. 3,585.—Riehle U. S. standard screw power testing machine for tensile specimens, 1 foot long or less, with 30 per cent. elongation for 1 foot specimens or more for shorter specimens.

being tabulated in a similar manner as indicated under the tension test.

Transverse Test.—This test is made as shown in fig. 3,584 by placing the specimen over two supports, loading the bar at a point midway between the supports, and noting the bending and breaking loads.



FIGS. 3,586 and 3,587.—***Single and double shear tests.*** The specimen is placed in the holder and the stress applied. The cutter shears the metal in a single plane for single shear and in two planes for double shear.

Shearing Test.—There are two kinds of shearing test according as the specimen is in *single* or *double* shear, as shown in figs. 3,586 and 3,587. In either case the test is made by cutting through the specimen and noting the load required for the operation.

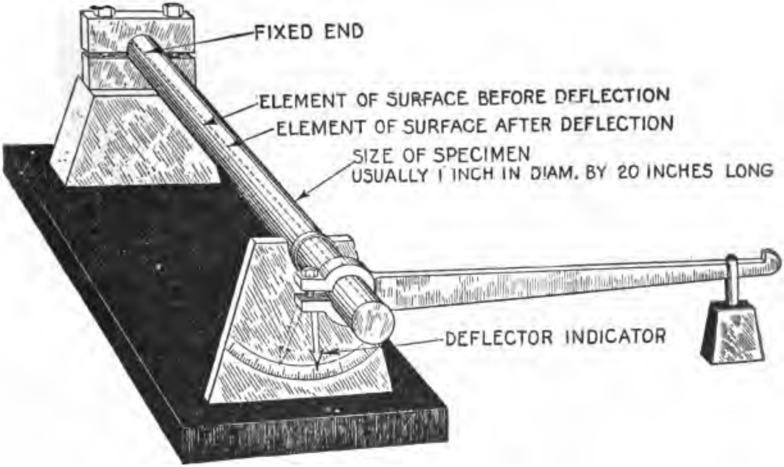

FIXED END
ELEMENT OF SURFACE BEFORE DEFLECTION
ELEMENT OF SURFACE AFTER DEFLECTION
SIZE OF SPECIMEN
USUALLY 1 INCH IN DIAM. BY 20 INCHES LONG
DEFLECTOR INDICATOR

Fig. 3,588.—***Tortion test.*** The specimen is gripped in the head so that it cannot turn and the deflector indicator attached; this end free to turn on the support. Tortion is applied by the weight, which twists the specimen in a clockwise direction, thus an element of its surface is distorted from a straight line, to a spiral form, the amount of distortion depending upon the intensity of the tortional force applied and the resisting power of the metal. By attaching at the deflection end, a suitable scale, the amount of twist can be read in degrees. The results sought in tortional tests are to determine the tortional elastic limit and ultimate tortional strength. Since the strain varies over the sectional area, it cannot be expressed as pounds per square inch, but must be stated as *inch pounds*. The value is obtained by multiplying the pull applied by the lever arm by the distance through which it acts. Thus if the weight be 100 pounds and the lever arm be 30 inches, then the tortional stress correspondingly is $100 \times 30 = 3{,}000$ inch-pounds. Again if the indicator register 20° on a 20-inch specimen the deflection in twist is stated as $20° \div 20$ inches $= 1°$ per inch.

Tortional Test.—If one end of a specimen be fixed and a twisting force be applied to the other end then an element of the surface which was straight before applying the force will assume a helical form.

Fig. 3,588 shows the method of making a test of this kind.

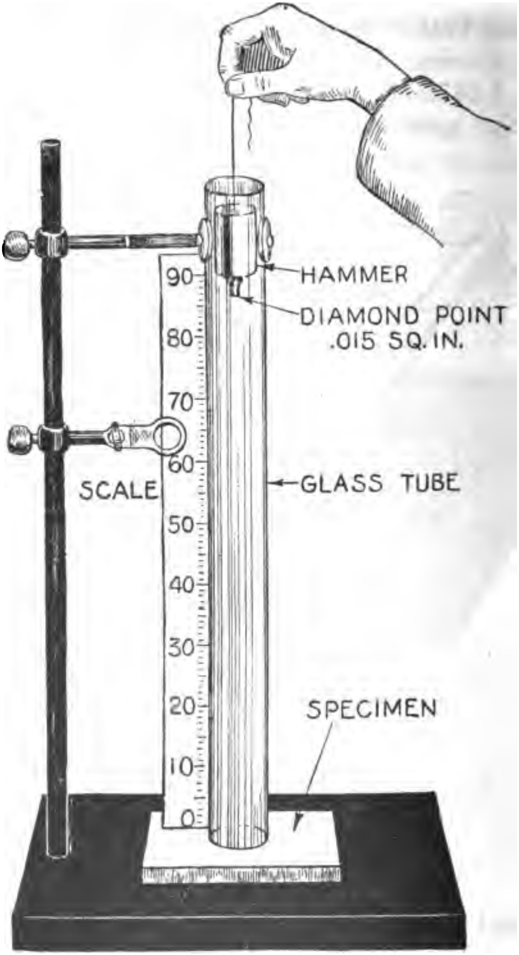
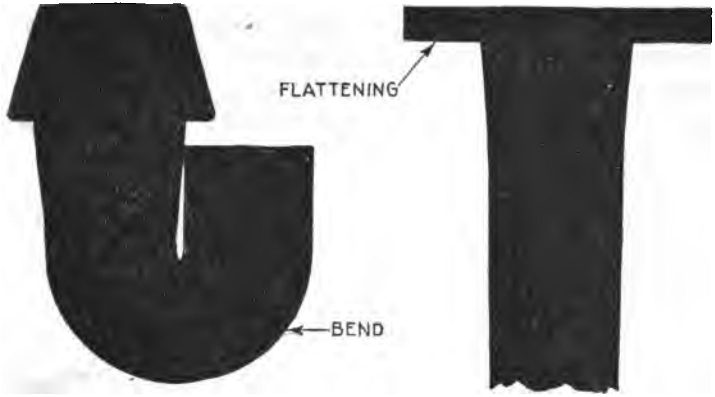


FIG. 3,589.—***Hardness test—rebound method.*** A hammer having a diamond point is placed in a glass tube and elevated 10 inches above the specimen. From this position the hammer is let drop upon the specimen and the rebound noted by aid of the scale. The higher the rebound the harder the material. This test is adapted for material of the same kind rather than those of different nature, because in some cases, the softer material will give a higher rebound.



FIGS. 3,590 and 3,591.—***A.S.M.E. cold bending and flattening test for rivets.*** In the cold bend test the rivet shank shall bend through 180° flat upon itself as shown, without cracking on the outside of the bent portion.

A.S.M.E. Tests—Requirements for boiler rivet steel.

44 *Tension Tests. a* The bars shall conform to the following requirements as to tensile properties:

Tensile strength, lb. per sq. in	45,000—55,000
Yield point, min., lb. per sq. in	.5 tens. str.
Elongation in 8 in., min., per cent	$\frac{1{,}500{,}000}{\text{Tens. str.}}$

but need not exceed 30 per cent.

b The yield point shall be determined by the drop of the beam of the testing machine.

45 *Bend Tests. a Cold-bend Tests*—The test specimen shall bend cold through 180 deg. flat on itself without cracking on the outside of the bent portion.

b Quench-bend Tests—The test specimen, when heated to a light cherry red as seen in the dark (not less than 1200 deg. fahr.), and quenched at once in water the temperature of which is between 80 deg. and 90 deg. fahr., shall bend through 180 deg. flat on itself without cracking on the outside of the bent portion.

46 *Test Specimens.* Tension and bend test specimens shall be of the full-size section of bars as rolled.

47 *Number of Tests. a* Two tension, two-cold bend, and two quench-bend tests shall be made from each melt, each of which shall conform to the requirements specified.

b If any test specimen develop flaws, it may be discarded and another specimen substituted.

c If the percentage of elongation of any tension test specimen be less than that specified in Par. 44 and any part of the fracture is outside the middle third of the gaged length, as indicated by scribe scratches marked on the specimen before testing, a retest shall be allowed.

48 *Permissible Variations in Gage.* The gage of each bar shall not vary more than .01 in. from that specified.

V WORKMANSHIP AND FINISH

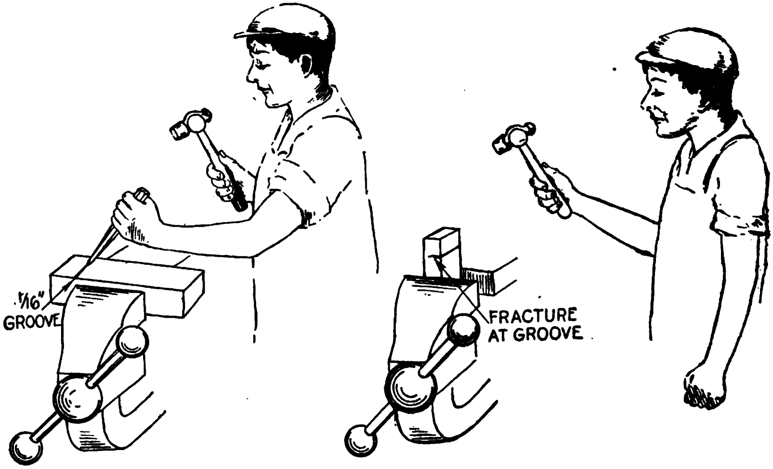
49 *Workmanship.* The finished bars shall be circular within .01 in.

50 *Finish.* The finished bars shall be free from injurious defects and shall have a workmanlike finish.

Hardness Test.—There are two methods of testing for hardness, as by: 1, pressing a hardened steel ball into the specimen under a fixed pressure, and noting the diameter of the indentation, and 2, letting a weight fall from a given height on the specimen, and noting the rebound.

In these tests the hardest material will have the smallest indentation and cause the highest rebound. Fig. 3,589 illustrates the rebound test.

Cold Bending Test.—The specimen is bent flat (that is



Figs. 3,592 and 3,593.—*A. S. M. E. homogenerty test.* Made by grooving and fracturing specmen; described in detail in accompanying text.

A. S. M. E. Tests—Requirement for Staybolt Steel.

63 Steel for staybolts shall conform to the requirements for Boiler Rivet Steel specified in Pars. 40 to 62, except that the tensile properties shall be as follows:

Tensile strength, lb. per sq. in	50,000—60,000
Yield point, min., lb. per sq. in	0.5 tens. str.
Elongation in 8 in., min., per cent	$\frac{1,500,000}{\text{Tens. str.}}$

Also with the exception that the permissible variations in gauge shall be as follows:

Permissible Variations in Gauge. The bars shall be truly round within 0.01 in. and shall not vary more than 0.005 in. above, or more than 0.01 in. below the specified size.

through 180°) either on itself or over a pin of given size as in figs. 3,590 and 3,591 and the condition of the metal at the bend noted.

Homogeneity Test.—In making this test, the specimen

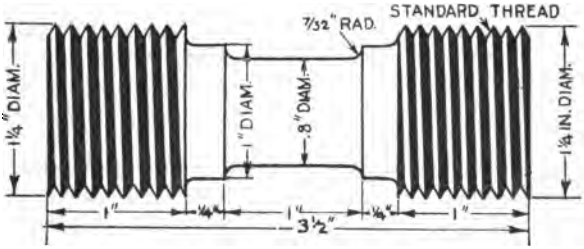


FIG. 3,594.—*A. S. M. E.* standard specimen required for tension tests of gray iron ***casting material.*** The quality of the iron going into casting under specification shall be determined by means of the above specimen, known as the *arbitration bar*. The tensile test is not recommended, but in case it be called for, the bar as here shown, shall be turned up from any of the broken pieces from the transverse test. The expense of the tensile test shall fall on the purchaser.

I PHYSICAL PROPERTIES AND TESTS

A. S. M. E. Tests—Requirements for Rivets.

55 *Tension Tests.* The rivets, when tested, shall conform to the requirements as to tensile properties specified in Par. 44, except that the elongation shall be measured on a gauged length not less than four times the diameter of the rivet.

56 *Bend Tests.* The rivet shank shall bend cold through 180 deg. flat on itself, as shown in fig. 2, without cracking on the outside of the bent portion.

57 *Flattening Tests.* The rivet head shall flatten, while hot, to a diameter 2½ times the diameter of the shank, as shown in fig. 3, without cracking at the edges.

58 *Number of Tests.* *a* When specified, one tension test shall be made from each size in each lot of rivets offered for inspection.

b Three bend and three flattening tests shall be made from each size in each lot of rivets offered for inspection, each of which shall conform to the requirements specified.

II WORKMANSHIP AND FINISH

59 *Workmanship.* The rivets shall be true to form, concentric, and shall be made in a workmanlike manner.

60 *Finish.* The finished rivets shall be free from injurious defects.

III INSPECTION AND REJECTION

61 *Inspection.* The inspector representing the purchaser shall have free entry, at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the rivets ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the rivets are being furnished in accordance with these specifications. All tests and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

62 *Rejection.* Rivets which show injurious defects subsequent to their acceptance at the manufacturer's works will be rejected, and the manufacturer shall be notified.

shall be either nicked with a chisel or grooved on a machine, transversely, about 1/16 in. deep, in three places about 2 in. apart.

The first groove shall be made 2 in. from the square end; each succeeding groove shall be made on the opposite side from the preceding one. The specimen shall then be firmly held in a vise, with the first groove about 1/4 in. above the jaws, and the projecting end broken off by light blows of a hammer, the bending being away from the groove. The specimen shall be broken at the other two grooves in the same manner.

The object of this test is to open and render visible to the eye any seams due to failure to weld or to interposed foreign matter, or any cavities due to gas bubbles in the ingot.

One side of each fracture shall be examined and the length of the seams and cavities determined, a pocket lens being used if necessary.

CHAPTER 64

SHELL BOILERS

In a shell boiler the water and steam are contained in a vessel usually of cylindrical form, most of the heating surface being composed of *fire tubes*, or flues as distinguished from the combination of drum and water tubes in the *water tube* boiler.

Ques. What is the difference between a fire tube and a water tube?

Ans. The hot gases pass inside of fire tubes and outside of water tubes, the water being outside of fire tubes and inside of water tubes.

Classes.—There are two great divisions of shell boilers, being classed with respect to the position of the furnace, according as it is:

1. Externally fired, or
2. Internally fired.

The multiplicity of types included in these two divisions are due to varied working conditions encountered. According to service all boilers may be divided into three classes.

1. Stationary*.
2. Locomotive.
3. Marine.

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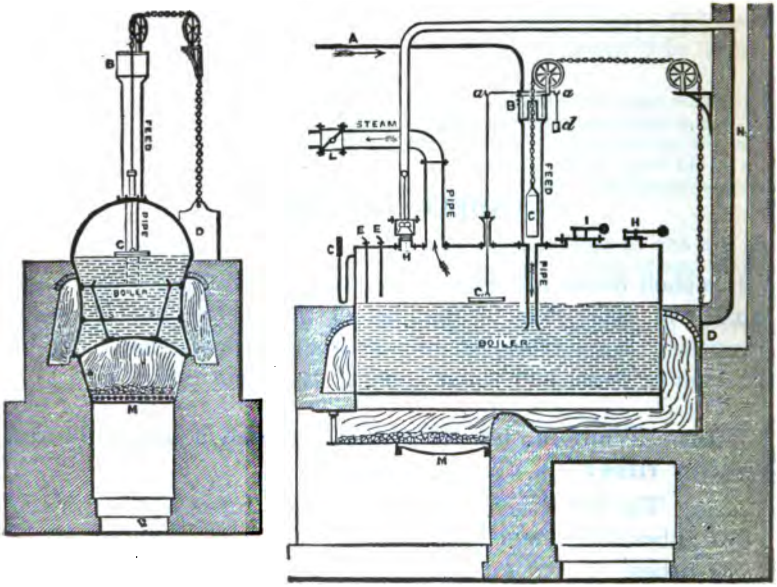
*NOTE.—The term "*stationary*" boilers is purely an American expression, the equivalent English term being "*land*" boilers.



FIGS. 3,595 and 3,596.—Watt's wagon boiler with split draught. ***In construction,*** it consisted of a cylindrical top, concave sides and a concave bottom. For the larger sizes, the grate was at one end of the boiler and the gases passed through an internal passage and then split, returning on each side of the boiler to the chimney which was in front. The sides were made concave more readily to form part of the side passages. The form of this boiler was, of course, not well adapted to withstand high pressures and soon gave way to the cylinder, which is the ideal form for high pressure work. As shown, A, is the supply pipe terminating in the cistern at the top of the feed pipe; B, cistern at the top of feed pipe, having a valve fixed at the bottom; C, the float employed to regulate supply of water to boiler. The water is kept at the same height by its action upon the valve at the bottom of the feed pipe; thus, when there is not sufficient water in the boiler, the float sinks, pulls down the arm of the lever *a*, *a*, to which it is attached, and opens the valve, since the counterbalancing weight *d*, fixed at the other end of the lever will only support the float when in its proper situation in the boiler and at the required level of the water. D, is a self acting damper for regulating the consumption of fuel; EE, gauge cocks; G, steam gauge; H, safety valve, regulated by the engineer; I, air valve, or atmospheric safety valve, U, the locked safety valve. A pipe is shown at the top which leads the steam that escapes into it to the flue or into the air. The steam passes from the boiler through the steam pipe, a valve, called a throttle valve L, being placed in it for regulating the amount of steam to the cylinder; M, furnace bars; N, flue; SS, stays.

NOTE.—The earliest boilers were spherical. These were made of cast iron and set in brickwork. It was customary to set this type of boiler with the fire underneath and construct flues in the brickwork to conduct the hot gases around the boiler just below the water level. The hot gases passed entirely around the boiler before escaping to the chimney.

1. EXTERNALLY FIRED BOILERS

Development of the Shell Boiler.—The early forms of shell boiler were of the externally fired class, the first of these being the wagon boiler brought out by James Watt as shown in figs. 3,595 and 3,596.

At this time the prime object was to get enough steam, no attention being paid to economy. These boilers were suitable for only very low pressure and were made of inferior metal.

After some experimenting it became apparent that the shape of the boiler must be changed to adapt it to higher pressures. To make it more economical, the heating surface was divided into smaller sections by inserting tubes or flues through which the hot gases passed, and later, to increase the strength, the boiler was made cylindrical.

At first, boilers were spherical, then of various shapes, some resembling a haystack, and others of more complex forms.

Following these came the plain cylinder, which, in development, was provided with one or two flues, and as more heating surface was demanded, the flues were reduced in size and increased in number; then a multiplicity of *tubes* were used as in the form commonly used at the present time.

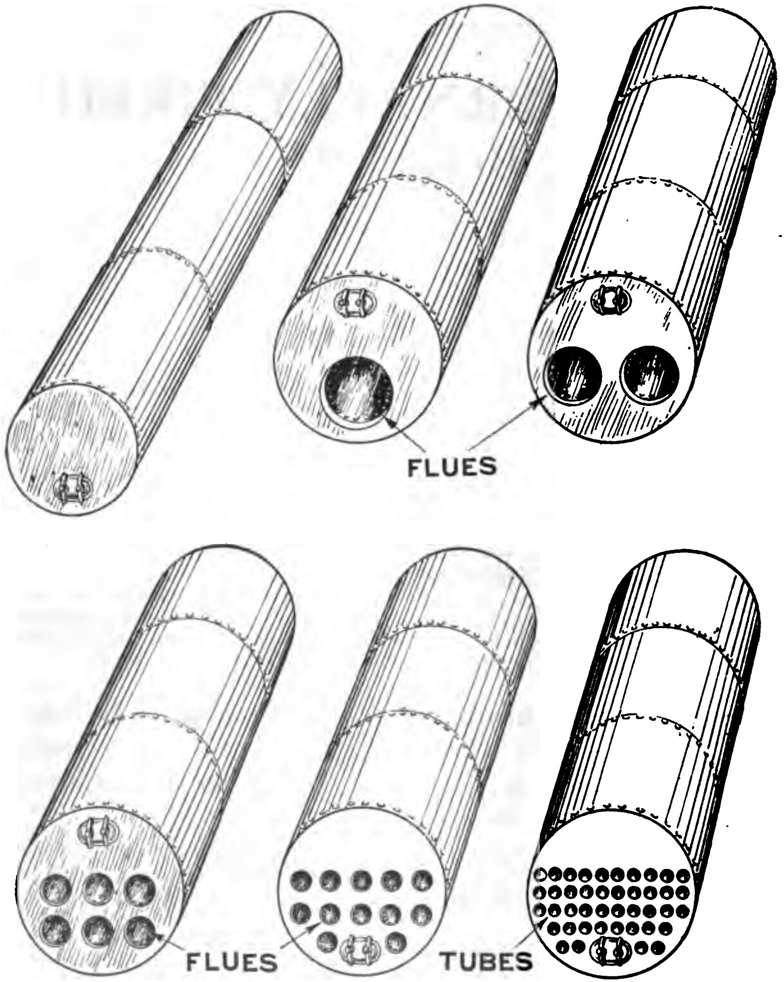
Ques. What is the difference between a flue and a tube?

Ans. A flue is of relatively large diameter and is *riveted* at its ends to the sheets. A tube is of relatively small diameter and is *expanded* into the sheets.

In tubular boilers sometimes a few heavy tubes are used which are *screwed* into the sheets to obtain additional strength. The erroneous use of the terms *flue* and *tube* should be avoided.

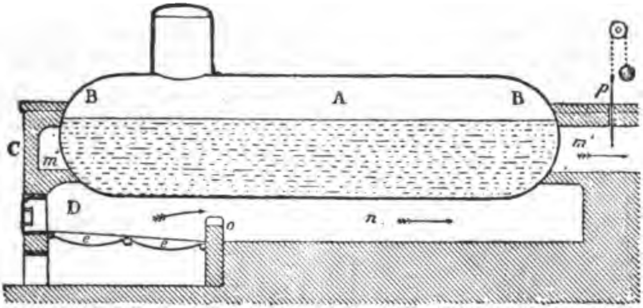
Ques. What are the sheets?

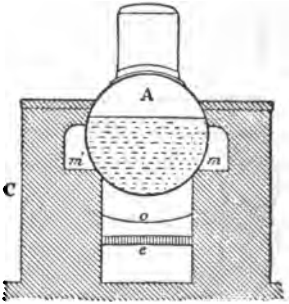
Ans. The boiler heads having circular holes for the flues or tubes and to which they are respectively riveted or expanded.



Figs 3,597 to 3,602.—Evolution of the modern "*horizontal return tubular boiler.*" Fig. 3,597, plain cylinder boiler; fig. 3,598, one flue; fig. 3,599, two flue; fig. 3,600, six flue; fig. 3,601, twelve flue; fig. 3,602, multi-tubular boiler.

The Horizontal Return Tubular Boiler.—This type is a development of the plain cylinder boiler, a shown in figs. 3,597 to 3,602. As shown the flues were first introduced, increased in





FIGS. 3,603 and 3,604.—Plain cylinder boiler. It consists of a cylinder A, formed of iron plate with hemispherical ends BB, set horizontally in brick work C. The lower part of this cylinder contains the water, the upper part the steam. The furnace D, is outside the cylinder, being beneath one end; it consists simply of grate bars *ee*, set in the brick work at a convenient distance below the bottom of the boiler. The sides and front of the furnace are walls of brick work, which, being continued upwards support the end of the cylinder The fuel is thrown on the bars through the door which is set in the front brick work. The air enters between the grate bars from below. The portion below the bars is called the ash pit. The flame and hot gases, when formed, first strike on the bottom of the boiler, and are then carried forward by the draft. to the so-called bridge wall *o*, which is a projecting piece of brick work which counteracts the area of the passage *n* and forces all the products of combustion to keep close to the bottom of the boiler. Thence the gases pass along the passage *n*, and return part one side of the cylinder in the passage *m* (fig. 3,064) and back again by the other side flue *m* to the far end of the boiler, whence they escape up the chimney. This latter is provided with a door or damper *p*, which can be closed or opened at will, so as to regulate the draught. The boiler has the advantages of cheapness, and convenience of cleaning since a man can get inside and clean and have access to all the interior surface. The large amount of water carried gives it large reserve capacity It is necessary, however, to obtain adequate heating surface that it be made very long. It is adapted to bad water and for blast furnace work when the long flame for the blast furnace has to be utilized. An important defect is that the temperature in each of the three passages *n*, *m*, *m*, is very different, and consequently that the metal of which the shell of the boiler is composed expands very unequally in each of the flues, and cracks are very likely to take place when the effects of the changes of temperature are most felt. It will be noted that the flames and gases in this earliest type of steam boiler make three turns before reaching the chimney, and as these boilers were made frequently as much as 40 feet long it gave the extreme length of 120 feet to the heat products.

number and diminished in size, finally a multiplicity of tubes usually 3 to 4 inches in diameter being used.

The heads above and below the tubes are stayed with diagonal and through stays.

Some of the tubes are also threaded and fitted with nuts to act as stays. It is, of course, necessary to provide a brick setting for this type of boiler.

The furnace is located at the front with a bridge wall immediately behind it and the combustion chamber for the combining of gases beyond.

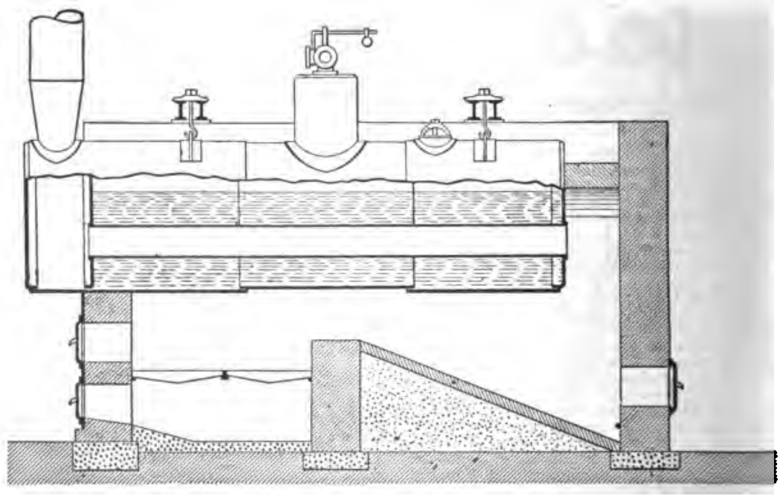
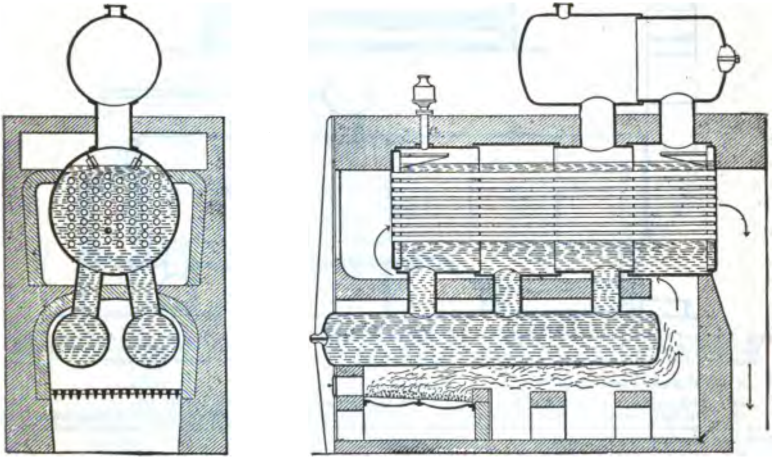


FIG. 3,605.—Single return flue boiler. To increase the heating surface, flues or internal return passages were introduced through which the gases should pass to the front of the boiler, locating the chimney at the front. This type has great storage capacity and a large increase of heating surface over the cylinder boiler, but the flues are an element of weakness, as they are subject to external pressure. The flue boiler is, therefore, not adapted to high pressure work. The flues act as braces for the heads. It was used for 10 to 60 pounds boiler pressure and from one to twelve flues were used, these being from 6 to 8 inches on diameter. For the larger sizes stiffening rings were put around the flues to prevent collapse.

Tubes are fastened to the heads by beading over the ends. The water line is carried from 3 to 4 inches above the upper tubes so that the amount which it may vary is comparatively small.

The numerous small tubes give a large amount of heating surface, but the brick setting introduces radiation.

It is rather difficult to clean this type of boiler. A manhole is provided at the top by which entrance can be had for cleaning and inspection, and hand holes are provided in the heads below the tubes for introducing scraping tools and for washing out sediment.

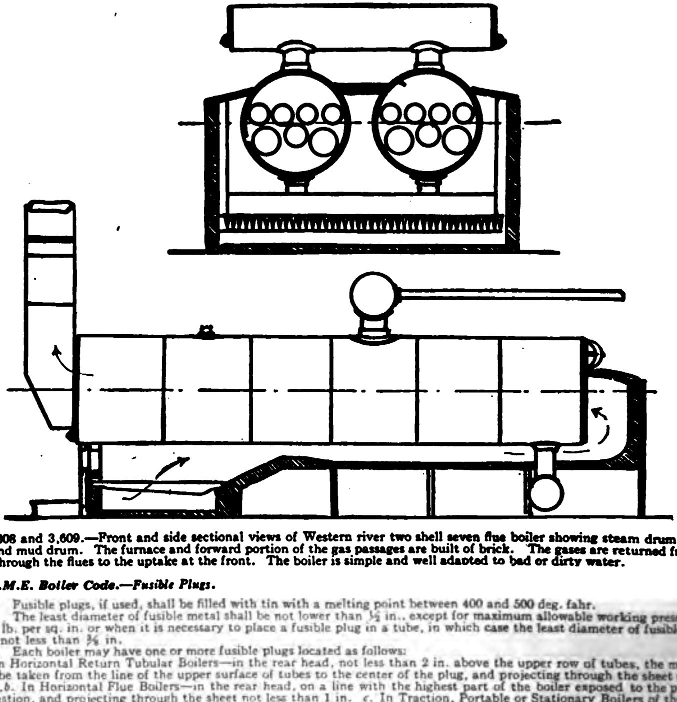


FIGS. 3,606 and 3,607.—Elephant boiler; a type used extensively in France. ***It consists of*** a tubular boiler placed above and connected by a series of necks to two cylinders or water "drums" as shown, a steam drum being similarly connected on top. The difficulty with this type is in getting good circulation, because the steam formed in the lower water drum cannot escape to the upper drum only through the necks. Hence where boiler is to be worked to capacity or forced, a liberal number of necks should be provided.

Sometimes enough of the lower tubes are omitted to furnish space for a manhole at the bottom. This is a very good feature, especially where dirty or scale forming water is used.

The tubes are usually arranged in vertical rows to facilitate circulation, leaving an extra wide space at the middle and next to the shell. In some designs the tubes are staggered vertically to render the heating surface more efficient.

The cost of this boiler is of course greater than the flue type, but somewhat less than the Cornish or Scotch types; this is offset, however, by the expense of the back setting.



Figs. 3,608 and 3,609.—Front and side sectional views of Western river two shell seven flue boiler showing steam drum, steam pipe and mud drum. The furnace and forward portion of the gas passages are built of brick. The gases are returned from the back through the flues to the uptake at the front. The boiler is simple and well adapted to bad or dirty water.

A.S.M.E. Boiler Code.—Fusible Plugs.

428. Fusible plugs, if used, shall be filled with tin with a melting point between 400 and 500 deg. fahr.

429. The least diameter of fusible metal shall be not lower than ½ in., except for maximum allowable working pressures of over 175 lb. per sq. in. or when it is necessary to place a fusible plug in a tube, in which case the least diameter of fusible metal shall be not less than ⅜ in.

430. Each boiler may have one or more fusible plugs located as follows:

a. In Horizontal Return Tubular Boilers—in the rear head, not less than 2 in. above the upper row of tubes, the measurement to be taken from the line of the upper surface of tubes to the center of the plug, and projecting through the sheet not less than 1 in. *b.* In Horizontal Flue Boilers—in the rear head, on a line with the highest part of the boiler exposed to the products of combustion, and projecting through the sheet not less than 1 in. *c.* In Traction, Portable or Stationary Boilers of the Locomotive Type or Star Water Tube Boilers—in the highest part of the crown sheet, and projecting through the sheet not less than 1 in. *d.* In Vertical Fire-tube Boilers—in an outside tube, not less than one-third the length of the tube above the lower tube sheet. *e.* In Vertical Fire-tube Boilers, Corliss Type—in a tube, not less than one-third the length of the tube above the lower tube sheet. *f.* In Vertical Submerged Tube Boilers—in the upper tube sheet, and projecting through the sheet not less than 1 in. *g.* In Water-tube Boilers, Horizontal Drums, Babcock & Wilcox Type—in the upper drum, not less than 6 in. above the bottom of the drum, over the first pass of the products of combustion, and projecting through the sheet not less than 1 in. *h.* In Stirling Boilers, Standard Tupe—in the front side of the middle drum, not less than 4 in. above the bottom of the drum, and projecting through the sheet not less than 1 in. *i.* In Stirling Boilers, Superheater Type—in the front drum, not less than 6 in. above the bottom of the drum, exposed to the products of combustion, and projecting through the sheet not less than 1 in. *j.* Water-tube Boilers, Heine Type—in the front course of the drum, not less than 6 in. above the bottom of the drum, and projecting through the sheet not less than 1 in. *k.* In Robb-Mumford Boilers, Standard Type—in the bottom of the steam and water drum, 24 in. from the center of the rear neck, and projecting through the sheet not less than 1 in. *l.* In Water-tube Boilers, Almy Type—in a tube or fitting exposed to the products of combustion. *m.* In Vertical Boilers, Climax or Hazelton Type—in a tube or center drum not less than one-half the height of the shell, measuring from the lowest circumferential seam. *n.* In Cahall Vertical Water-tube Boilers—in the inner sheet of the top drum, not less than 6 in. above the upper tube sheet, and projecting through the sheet not less than 1 in. *o.* In Wickes Vertical Water-tube Boilers—in the shell of the top drum and not less than 6 in. above the upper tube sheet, and projecting through the sheet not less than 1 in; so located as to be at the front of the boiler and exposed to the first pass of the products of combustion. *p.* In Scotch Marine Type Boilers—in the combustion chamber top, and projecting through the sheet not less than 1 in. *q.* In Dry Back Scotch Type Boilers—in the rear head, not less than 2 in. above the upper row of tubes, and projecting through the sheet not less than 1 in. *r.* In Economic Type Boilers—in the rear head, above the upper row of tubes. *s.* In Cast-Iron Sectional Heating Boilers—in a section over and in direct contact with the products of combustion in the primary combustion chamber. *t.* In Water-tube Boilers, Worthington Type—in the front side of the steam and water drum, not less than 4 in. above the bottom of the drum, and projecting through the sheet not less than 1 in. *u.* For other types and new designs, fusible plugs shall be placed at the lowest permissible water level, in the direct path of the products of combustion, as near the primary combustion chamber as possible.

NOTE.—Fire Engine Boilers are not usually supplied with fusible plugs. Unless special provision be made to keep the water above the fire box crown sheet other than by the natural water level, the lowest permissible water level shall be at least 8 in. above the top of the fire box crown sheet.

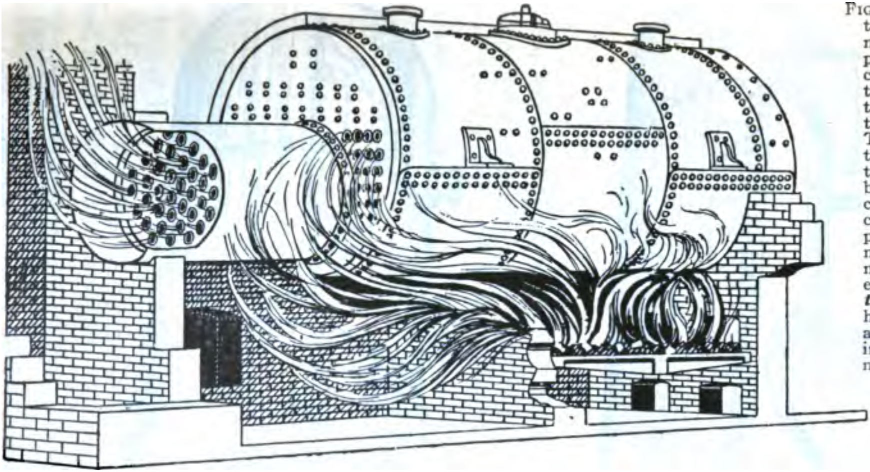
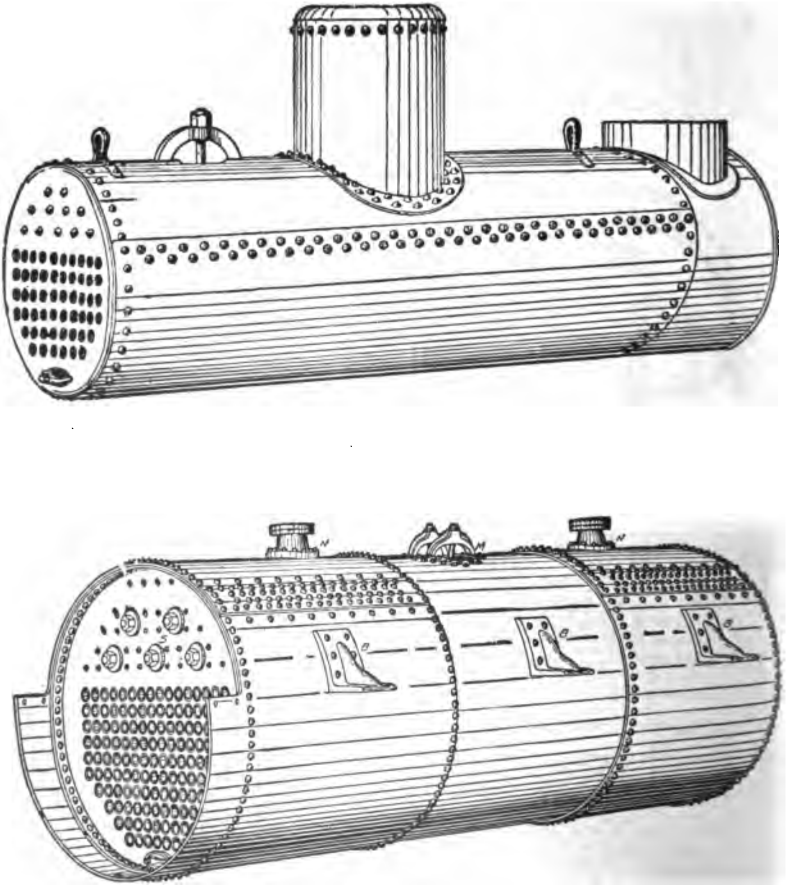


FIG. 3,610.—Three pass tubular boiler. This method of leading the products of combustion causes them to travel the boiler length three times before passing out through the chimney. This is accomplished by the small extension to the shell seen at the back of the boiler. The cut shows clearly the curve of the gases in passing from the furnace to the chimney, making two reversals en route. ***The advantages claimed are:*** 1, higher furnace temperature without increase in stack temperature; 2, nearer uniform expansion; 3, better heat distribution; 4, more convenient location for outlet for product of combustion.

NOTE.—***Conditions of Fuel Economy in Steam Boilers.***—1. That the boiler has sufficient heating surface to absorb from 75 to 80 per cent. of all the heat generated by the fuel. 2. That this surface is so placed, and the gas passages so controlled by baffles, that the hot gases are forced to pass uniformly over the surface, not being short circuited. 3. That the furnace is of such a kind, and operated in such a manner that the fuel is completely burned in it, and that no unburned gases reach the heating surface of the boiler. 4. That the fuel is burned with the minimum supply of air required to insure complete combustion, thereby avoiding the carrying of an excessive quantity of heated air out of the chimney. There are two indices of high economy: 1, high temperature, approaching 3,000° F. in the furnace, combined with low temperature, below 600° F., in the flue, and 2, analysis of the flue gases showing between 4 and 8 per cent. of free oxygen. Unfortunately neither of these indices is available to the ordinary fireman; he cannot distinguish by the eye any temperature above 2,000° and he cannot know whether or not an excessive amount of oxygen is passing through the fuel. The ordinary haphazard way of firing therefore gives an average of about 10 per cent lower economy than can be obtained when the firing is controlled, as it is in many large plants, by recording furnace pyrometers, or by continuous gas analysis, or by both. Low CO_2 in the flue gases may indicate either excessive air supply in the furnace, or leaks of air into the setting or deficient air supply with the presence of CO, and therefore imperfect combustion. The latter, if excessive, is indicated by low furnace temperature. The analysis for CO_2 should be made both of the gas sampled just beyond the furnace and of the gas sampled at the flue. Diminished CO_2 in the latter indicates air leakage. Less than 4 per cent of free oxygen in the gases is usually accompanied with CO, and it therefore indicates imperfect combustion from deficient air supply. More than 8 per cent. means excessive air supply and corresponding waste of heat.



Figs. 3,611 and 3,621.—Horizontal return tubular boiler with and without steam dome. Preferable to a steam dome is a dry pipe. This pipe should extend nearly the entire length of the boiler so as to collect the steam over an extended surface thus avoiding as much moisture as possible. The author's dry pipe for vertical boiler is shown in fig. 3,634.

The general features of the horizontal tubular boiler are illustrated in figs. 3,611 and 3,612, showing boiler with and without dome. The methods of "setting" the boiler are explained in the chapter on Boiler Settings.

2. INTERNALLY FIRED BOILERS

The waste by radiation from the externally fired boiler setting was early observed by ***Trevithick,*** a Cornish engineer, who in order to overcome this adopted the expedient of putting the furnace inside a large flue, and, *as usual*, instead of receiving credit for this improvement, it became known as the Cornish boiler.

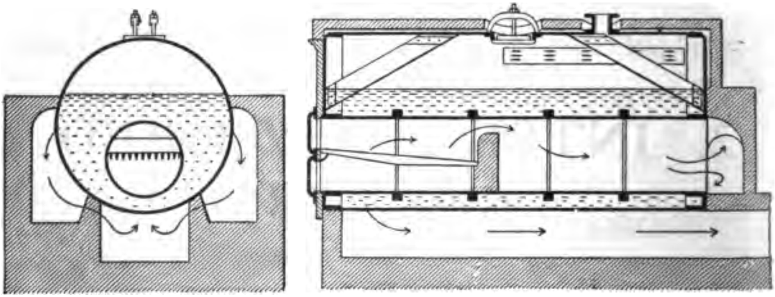
Trevithick or So-called Cornish Boilers.—By placing the furnace inside a large flue running the length of the boiler Trevithick not only succeeded in reducing the loss by radiation, but obtained additional heating surface, thus permitting a reduction in length as compared with the plain cylinder boiler.

Oliver Evans used this type as early as 1800, and in England it led to the internally fired flue boilers which are still extensively used in the small and medium sizes.

The general construction is shown in figs. 3,613 and 3,614. With increasing pressures it was necessary to support the flat heads, and diagonal or gusset stays of the type here indicated were used.

The necessity of providing room for the furnace within the boiler shell also made it necessary to increase the diameter of the boiler and although the flue acted as a stay for the lower part of the heads, the upper parts needed support.

Ordinarily the flue is made .6 the diameter of the shell, the space underneath the flue is about 6 inches, and the length of the boiler is five to six



FIGS. 3,613 and 3,614.—***Trevithick*** or so called Cornish boiler introduced in Cornwall. ***It consists of*** a cylindrical shell having a large flue running the length of the boiler and in which is placed the furnace as shown, the grates resting at one end on a brick wall and at the other on a support riveted to the front of the flue. By this arrangement the sediment was allowed to fall to the bottom of the boiler where the temperature was low so that it did less harm than in the cylinder type, where it fell on the hottest part. The hot gases pass from the fire through the flue where they divide and return through the passages M and S, thence they unite and traverse again the length of the shell through the passage L, which leads to the chimney. The heads of the boiler are reinforced by gusset stays. To provide for excess expansion of the flue it was found necessary to build up the flue in sections with flanges at the ends. The sections being riveted to plain rings, known as Adamson rings, shown in detail in fig. 0021.

NOTE.—***Richard Trevithick,*** born 1771, died 1833, was a noted English mechanical engineer. He invented the Trevithick, or so called Cornish, boiler and was the first to apply steam for drawing loads on railroads. He was especially noted for his inventive genius and herculean strength. He made various improvements in pumps; invented a double acting water pressure engine (1800), a steam road carriage (1801); improved the locomotive for operating on rails (1808); adapted the steam engine to mining, and made many experiments in engines for dredging, marine propulsion and other purposes.

NOTE.—***Trevithick boiler.***—Diameter usually about $^1/_6$ of the length; a common proportion is 36 to 40 feet in length and from 6 to 7 feet in diameter. Steam pressure from 15 to 35 lbs.

times its diameter. The expansion of the flue, which is greater than that of the shell, caused trouble, making it necessary to introduce expansion joints as shown in fig. 3,614.

For very large boilers, the diameter of the flue had to be considerably increased in order to get sufficient grate surface, which led to the use of two flues, their arrangement being called the Lancashire boiler.

Lancashire Boiler.—This may be defined as a *two furnace **Trevithick** boiler*. It was constructed to adapt the Trevithick boiler to larger sizes by providing additional grate area and yet not increasing the length of the boiler.

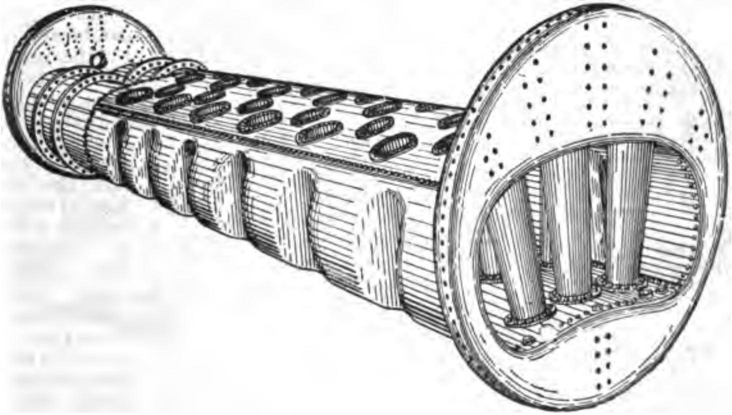
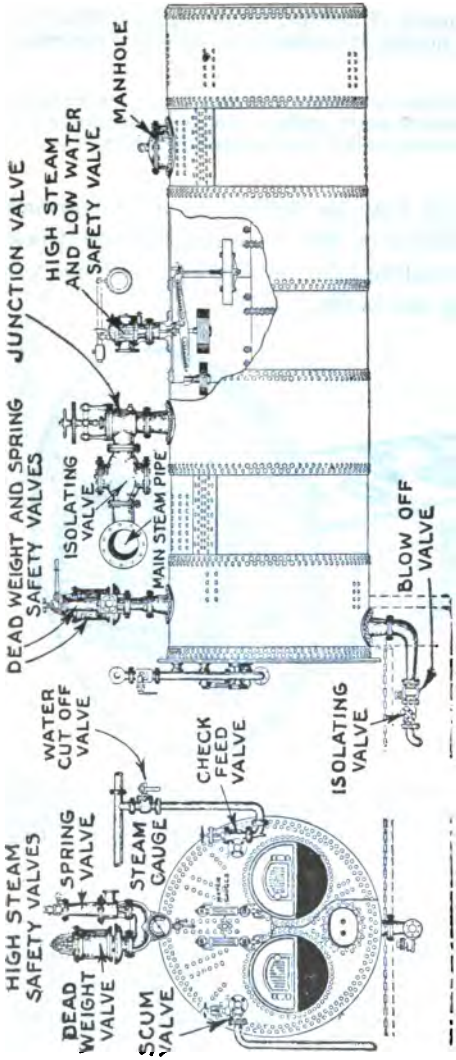


FIG. 3,615.—Galloway flue. ***In construction*** it has corrugated sides and the conical tubes are staggered, thus insuring a thorough breaking up of the currents of hot gases. The tubes are made conical to facilitate removal for repairs. They are more generally riveted than welded, because the removal of a tube that is welded leaves a large hole in the flue. Other details of the Galloway boiler are shown in the accompanying cuts.

NOTE.—***Cornish boiler.*** By reason of the large diameter of the flue and its liability to collapse under a high pressure, the latter was formerly restricted to 45 pounds steam pressure, but with improved construction these boilers are now made for any ordinary pressure, though commonly not more than 100 pounds. The principal dimensions of the ordinary sizes used in England are: ***diameter of shell,*** 3 feet 6 inches, 4 feet 3 inches, 5 feet, 5 feet 6 inches, 6 feet; ***length,*** 8 feet, 12 feet, 15 feet, 18 feet, 22 feet; ***diameter of flue,*** 2 feet 2 inches, 2 feet 4 inches, 2 feet 9 inches, 3 feet 3 inches, 3 feet 6 inches. A test of a Cornish boiler 6 feet by 28 feet gave an efficiency of 77%—*Barr.*



Figs. 3,616 and 3,617.—Lancashire boiler without breeches. It is of the same construction as the Trevithick, but has two furnace flues. It is shown complete with all its mountings. First, there is the manhole for providing access to the boiler; then the safety valve, which blows off when steam pressure is too high, and blows off also when the water level is too low—the float hung on the balance sinks as the water falls in level and pulls open the valve. The main stop valve is on the junction of the steam pipe, and an isolating valve to cut off communication automatically from other boilers when by any cause the pressure should fall in this boiler. There is also a dead weight and spring safety valve, which are adjusted and locked so that they guard against any tampering with the high and low safety valve. In front there is the pressure gauge and two water gauges, feed water valve, scum valve, manhole and blow off valve. The scum valve blows off from the surface all floating impurities, and the blow off valve is for clearing out mud and sediment collecting at the bottom.

When the shell of a Trevithick boiler exceeds say six feet in diameter, the flue assumes such large proportions that it has to be made very heavy to secure adequate strength to prevent collapse. Hence, as a proper width of grate can be secured by the use of two smaller flues without the risks attending the use of one large flue the two flue arrangement is a better construction. Moreover, better combustion is secured because the alternate method of firing can be employed. In this method, first one furnace is fired, then the other with the result that the unburned gases issuing from the fresh fuel from one furnace are ignited in the external passage

by the burning gases preceeding from the other furnace. Thus the waste of fuel due to unburned gases is avoided, if the firing be properly done.

Ques. What are the disadvantages of the Lancashire boiler?

Ans. **1**, Difficulty in the medium sizes, of finding adequate room for the two furnaces without unduly increasing the diameter of the shell; **2**, low furnaces are unfavorable to complete combustion, the comparatively cold crown plates, when they are in contact with the water of the boiler, tending to extinguish the flames from the fuel, when they are just formed; **3**, the narrow space between the fuel and the crown does not admit the proper quantity of air being supplied above the fuel to complete the combustion of the gases, as they arise; **4**, danger (in very large sizes) of collapse of the flues.

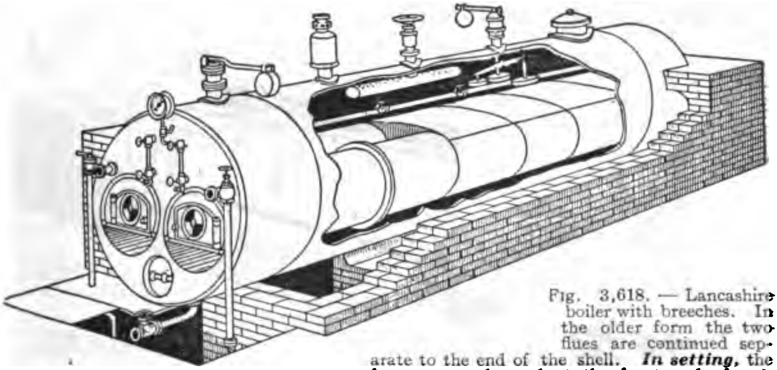
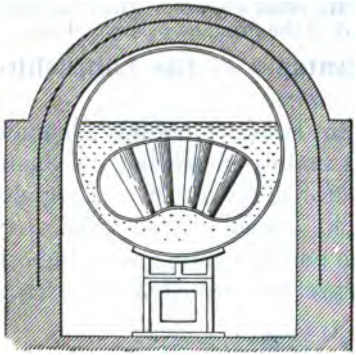


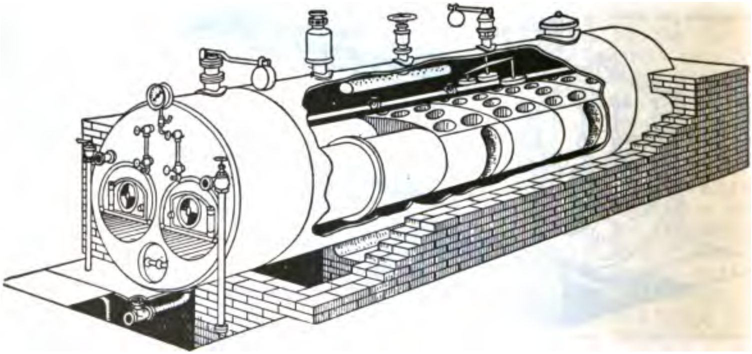
FIG. 3,618. — Lancashire boiler with breeches. In the older form the two flues are continued separate to the end of the shell. ***In setting***, the furnaces are located at the front end of each flue and the gases pass downward at the back end into a central passage which runs under the bottom of the shell to the front where the stream divides and passes through the two side passages, thence to chimney. Sometimes the flues are arranged so that the gases pass down the side of the shell before going under the bottom, but this plan does not heat the water in the lower part of the boiler when raising steam as fast as the former. ***Characteristics***, usual proportions give heating surface ratio 25:1; adapted to dirty and impure water; slow steam raising, but large reserve capacity; poor circulation; boiler bulky per horse power rendering it unsuitable for basements of buildings.

Ques. Describe a "breeches flued" Lancashire boiler and what is the object sought?



Ans. In this construction, the two flues instead of running the full length of the boiler merge into one large flue which forms a combustion chamber, and secures better combustion.

The combustion chamber or the *breeches*, increases the space, but the construction at the junction of the two flues is weak and has been responsible for many explosions.



FIGS. 3,619 and 3,620.—Galloway boiler showing breeches and Galloway flues. In the breeches are riveted a number of conical water flues, tapering from about 9 inches to 4½ inches diameter which forms the distinguishing feature of the Galloway boiler. These flues which in consequence of the taper form can be easily renewed if required, increase the heating surface, and help circulation.

Galloway Boiler.—A third modification of the Trevithick boiler is the Galloway as shown in the accompanying cuts. The

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NOTE.—Both the Trevethick and Lancashire types on account of economy of fuel and ease of cleaning out have been used extensively in the mining regions of England, where the water is extremely bad.

NOTE.—***The principal dimensions*** of the three leading sizes of Lancashire boiler used in England, are, according to *Barr:* ***diameter shell,*** 6 feet, 6 feet 6 inches, 7 feet; ***length,*** 20 feet to 28 feet; 20 feet to 30 feet; 21 feet to 30 feet; ***diameter flues,*** 2 feet 3 inches, 2 feet 6 inches, 2 feet 9 inches.

object sought in this design was to overcome the defects of the Lancashire boiler by providing obstruction in the flues.

These obstructions or cross flues, as shown in fig. 3,621 were called Galloway flues, and the results obtained by their use were: 1, multi-deflection of the hot gases securing a more intimate mixture of same, giving better combustion; 2, additional heating surface, and 3, better circulation.

The improved circulation reduced the difference of temperatures in the upper and lower parts of the boiler, thus overcoming a serious objection to the Lancashire boiler.

There are two forms of Galloway boilers, the one having two distinct flues, and the other a breeches flued arrangement similar to the Lancashire type, but with the breeches perforated with Galloway flues.

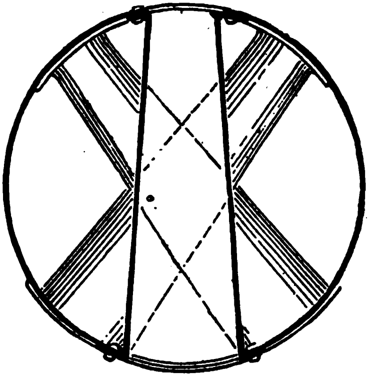
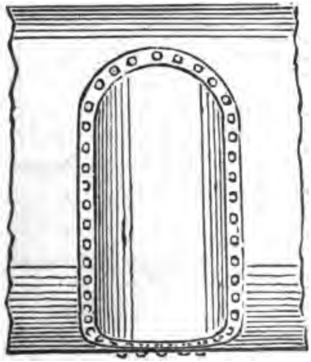
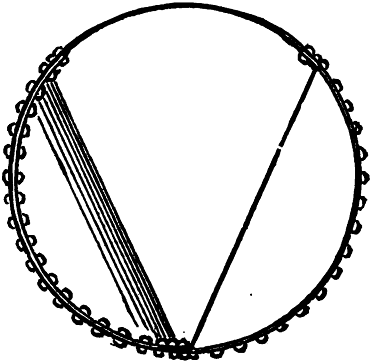


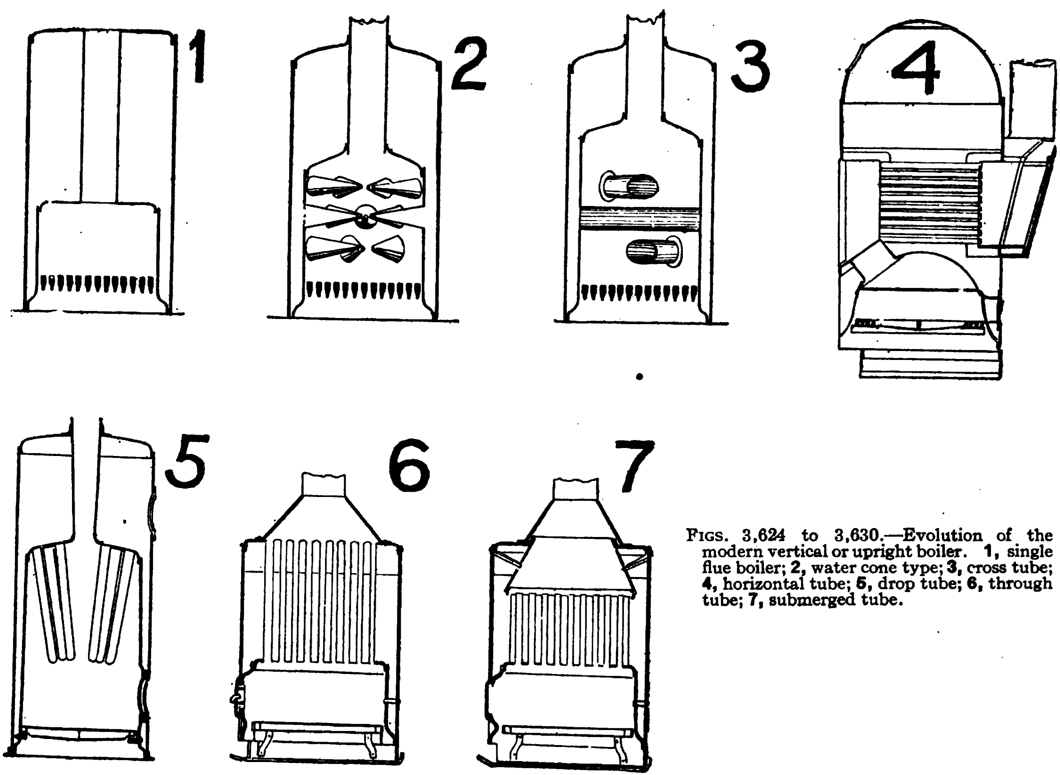
FIG. 3,621.—Galloway flues (so called "tubes"). As arranged in independent or through flue. *In construction,* the Galloway flue is tapered to permit the lower flange being inserted in the upper opening to get the flue into place. Many makers insert cylindrical pipes and weld them to the flue. Figs. 3,619 and 3,620 show arrangement of Galloway flue in the breeches.

Vertical or "Upright" Boiler.—Where floor space is





FIGS. 3,622 and 3,623.—Petrie's water pockets introduced into large flues as a precaution against collapse, in addition to acting as promoters of circulation.



FIGS. 3,624 to 3,630.—Evolution of the modern vertical or upright boiler. **1**, single flue boiler; **2**, water cone type; **3**, cross tube; **4**, horizontal tube; **5**, drop tube; **6**, through tube; **7**, submerged tube.
]]>

valuable and there is sufficient height, a vertical boiler is generally used. In early times this boiler had only a single flue, and then additional flues were added gradually increasing the heating surface until the modern tubular form was reached. In this form nearly all the members are of cylindrical shape and arranged vertically, the gases passing direct from the furnace through the tubes to the stack. Vertical boilers may be divided into two general types, with respect to the tubes:

1. ***Through*** tube
2. ***Submerged*** tube.

Ques. Describe a through tube vertical boiler?

Ans. An outer cylindrical shell encloses the water and steam space. Within this shell is a smaller cylinder extending about one-third way up which forms the furnace and combustion chamber and ash pit. The cylindrical furnace is flanged out at

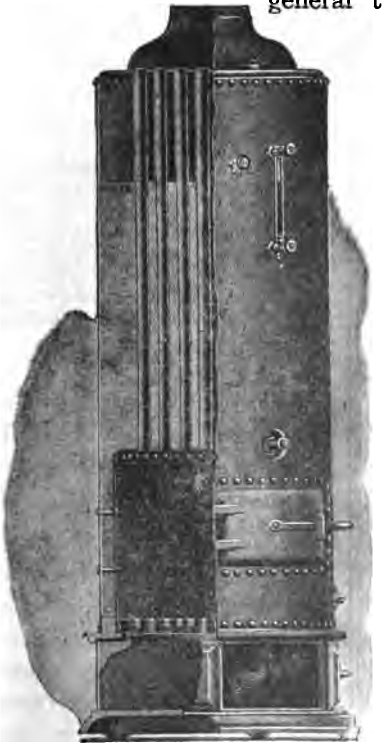


FIG. 3,631.—Bigelow *through tube* stationary vertical boiler as built in sizes from 3 to 100 horse power.

NOTE.—***Through tube vertical boiler.*** There has been too much adverse criticism of this type of boiler. The trouble is not with the boiler but with the critics. The bad reputation of this boiler is due to ignorance in handling and the absence of a steam collector or dry pipe. To prevent burnt tube ends, the water should be carried at the highest practical level. In getting up steam the boiler should be entirely filled with water and when steam forms blow down to working level. The author operated a 6'×9' vertical marine boiler in this way several seasons and had no tube trouble whatever. On page 2,406, is shown the author's separating, collecting and drying devices for carrying abnormally high water level in through tube vertical boilers. ***Another reason*** for carrying high water level is because ***the heating surface in contact with the water is more efficient than that in contact with the steam.***

the bottom until it meets the outer shell, dispensing in this way, with a lower head. In one side it flanges to the shell to form an opening for furnace door; the top is flat and into which are expanded a multiplicity of vertical tubes, the upper end of which are expanded into a similar flat surface at the top of the shell. These flat surfaces are called respectively the lower and upper tube sheets.

The cylindrical furnace is stayed to the outer shell by a proper number of stay bolts, thus strengthening it against collapse. The development and construction of vertical boilers is shown in the accompanying illustration.

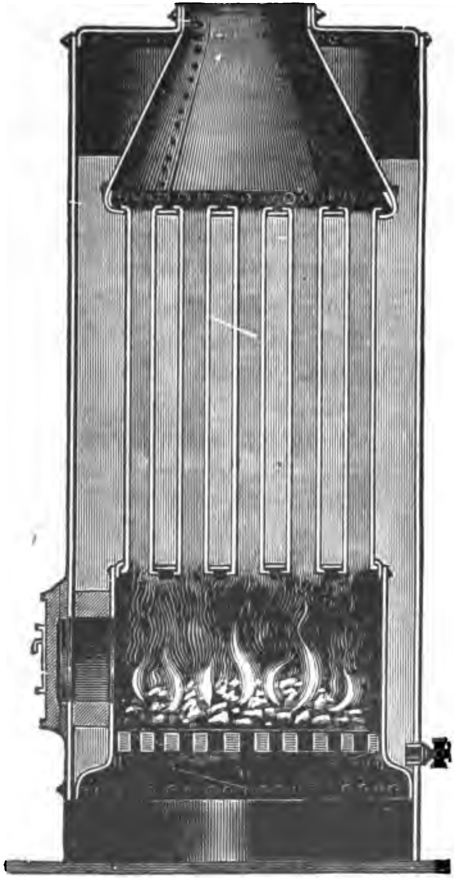


FIG. 3,632.—Small ordinary ***submerged tube*** stationary vertical boiler as built in sizes from 4 to 50 horse power.

Ques. What are the defects of vertical boilers as ordinarily constructed?

Ans. Poor circulation, liability to foam, tubular heating surface above water line inefficient, less economical than other types, liability to burn upper ends of tubes by ignorant handling; small steam space, lower tube sheet inaccessible for cleaning, greater risk of explosion due to sediment on lower tube sheet.

Submerged Tubes.—Frequently vertical boilers are constructed with submerged tubes, that is the top head of the shell is riveted to a conical shaped submerging chamber of sufficient depth that the upper tube sheet attached to its lower flange is below the water level.

The author objects to this construction because with proper management it is not necessary and moreover, it complicates the construction and renders the upper tube sheet less accessible.

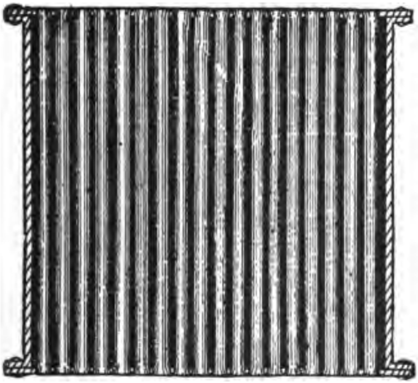


FIG. 3,633.—Extreme practice in vertical boiler construction illustrating the great amount of heating surface that can be crowded into a small space, with very little weight. This boiler as used on the Stanley steam automobile, has a shell made of seamless pressed steel, and reinforced by two layers of piano wire wound around its exterior under tension. The upper head is part of the pressed steel shell. This cut gives a section through the center showing one row of tubes. An exterior view of the boiler is shown on page 1,965. The tubes are usually made of copper which possesses a superior heat conducting property. The tables below give dimensions of such boilers as usually constructed for automobiles and trucks.

AUTOMOBILE BOILERS.
(Seamless Shells.)

Internal Diam. In.	Thickness of Shells In.	Number of ½ inch Tubes.	Length of Tubes In.	Actual Horse Power.	Approximate Weight in Pounds.
14	[illegible]/16	309	13½	4 [illegible]/16	112
16	[illegible]/16	420	13½	5 [illegible]/16	146
16		420	13½	5 [illegible]/16	154
17	[illegible]/16	460	13½	6 [illegible]/16	158
17		480	18½	6 [illegible]/16	174
18	[illegible]/16	529	13½	7 [illegible]/16	180
18		529	13½	7 [illegible]/16	196
19	[illegible]/16	586	13½	8 [illegible]/16	203
19		586	13½	8 [illegible]/16	222
20	[illegible]/16	676	13½	10 [illegible]/16	231
20		676	13½	10 [illegible]/16	257
20		676	14½	11 [illegible]/16	272
20		676	15½	12 [illegible]/16	287
20		676	16½	13	302
23		850	13½	12	293
23		850	14½	13	312
23		850	15½	14	331
23		850	16½	14 [illegible]/16	350

The sixteen, seventeen, eighteen and nineteen-inch boilers listed above are made with tubes fourteen, fifteen, sixteen seventeen and eighteen inches long, which approximately increases the horse power in proportion as the tubes increase in length.

HEAVY TRUCK BOILERS.
(Welded Shells.)

Internal Diam. In.	Thickness of Shells In.	Number of ½ inch Tubes.	Length of Tubes In.	Actual Horse Power.	Approximate Weight in Pounds.
22	[illegible]/16	825	13½	11 [illegible]/16	332
22	[illegible]/16	825	16	14 [illegible]/16	354
22	[illegible]/16	825	20	17 [illegible]/16	390
23	[illegible]/16	850	18	16 [illegible]/16	384
23	[illegible]/16	850	22	19 [illegible]/16	420
23	[illegible]/16	850	23	20 [illegible]/16	464
24	[illegible]/16	951	13	13 [illegible]/16	365
24	[illegible]/16	951	16	16 [illegible]/16	433
24	[illegible]/16	951	18	18 [illegible]/16	472
24	[illegible]/16	951	20	20 [illegible]/16	525
24	[illegible]/16	951	22	22 [illegible]/16	566
24	[illegible]/16	951	23	23 [illegible]/16	590
24	[illegible]/16	951	24	24 [illegible]/16	608
24	[illegible]/16	951	26	28	659
24	[illegible]/16	951	28	29	700
24	[illegible]/16	951	30	31 [illegible]/16	742
28	[illegible]/16	1320	16	23	675
28	[illegible]/16	1320	20	28 [illegible]/16	844
30	[illegible]/16	1470	16	25 [illegible]/16	850
30	[illegible]/16	1470	20	32 [illegible]/16	890

If the boiler be full of water in raising steam, and carried at the proper level during operation there will be no trouble with the tubes, as has been demonstrated by the author's experience with this type of boiler.

Ques. What should be insisted upon in ordering a vertical boiler, and why?

Ans. The steam outlet should be provided with a circular dry pipe extending around the tubes so that the water may be carried at proper height to protect the tubes and yet obtain dry steam.

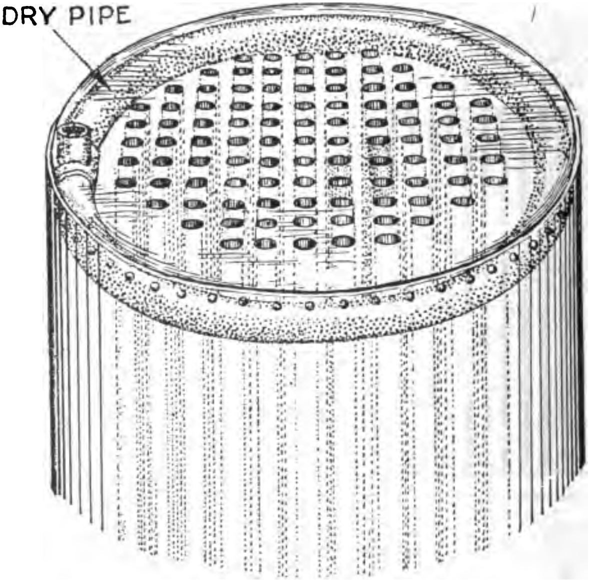


FIG. 3,634.—Author's dry pipe arranged to collect steam around the entire circumference of shell, thus permitting a high water level to protect the tubes, and increase the efficiency of the heating surface while insuring dry or practically dry steam and protection for priming on sudden heavy demand for steam.

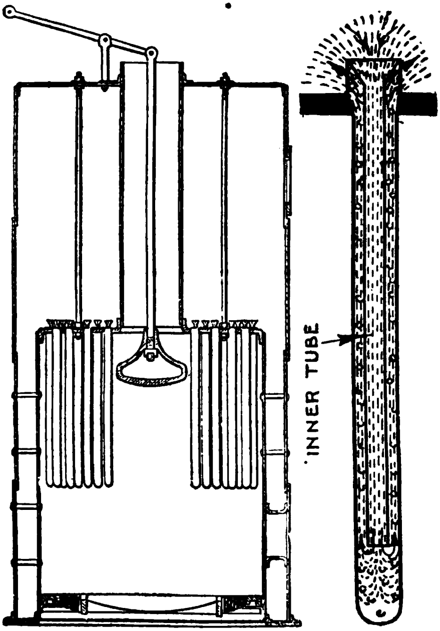
The water level should be carried high not only to protect the tubes but to render more of the tube area effective heating surface.

Locomotive Boilers.—These boilers are of cylindrical form through most of the length of the shell, and in the tubes, while the furnace and forward portion of the shell are constructed in box form. The tubes are arranged horizontally and the gases pass directly from the furnace in the front through the tubes to the rear of the boiler and to the smoke stack. The principal parts of a locomotive boiler are:

1. The shell, consisting of two parts, a cylindrical one in wake of the tubes and the front part with rounded top on a box shaped lower half.

2. The furnace and combustion chamber, with the grate in the open bottom, opening through the water space at the front, with the furnace door. It is separated from the shell and the heads by water spaces. The sides and the sometimes flat, sometimes rounded, top require staying to a large extent. The sides, at the bottom, are sometimes flanged to the shell and heads, and sometimes connected to them by a solid, forged ring of the thickness of the water space.

3. Cylindrical tubes in large number and relatively small diameter, which connect the furnace to the rear head of the shell.



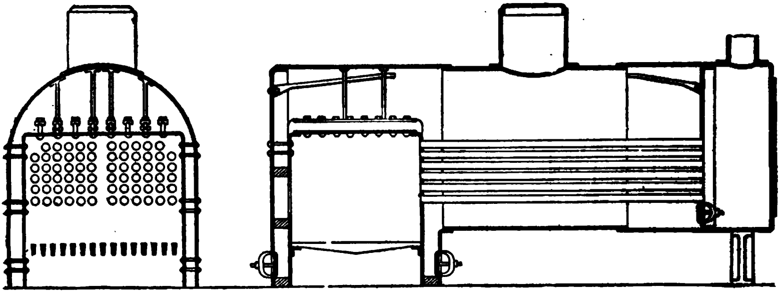
FIGS. 3,635 and 3,636.—Edward Field "drop tube" boiler and detail of tube. This is a combination shell and water tube boiler. ***In construction,*** a large number of tubes are expanded into the tube sheet as shown being closed at the lower end and opening at the upper end into the water space. Within each tube is another tube open at both ends as shown in fig. 3,636. It is so suspended that a rapid circulation takes place, the steam and heated water rising in the outer tube, and the relatively colder (and heavier) water descending in the inner tube as indicated by the arms. The upper end of the inner tubes are flared to promote circulation. This boiler, according to one maker requires clean feed water, is rather heavy and expensive, but safe and easily cared for.

4. Front and back heads to complete water and steam space; also a sheet, called the throat sheet, connecting the cylindrical shell at the bottom to the box portion.

Ques. What are the chief differences in locomotive boilers?

Ans. They vary mostly in the shape of the furnace and the location of the grate; they are either straight or wagon top.

Ques. Describe the wagon top construction.



FIGS. 3,637 and 3,638.—Semi-portable locomotive boiler for stationary service. ***In construction,*** the fire box is surrounded by a water space of 3 or 4 inches. The use of flat plates subject to pressure makes it necessary to stay the surfaces of the furnace and this is done at the sides and back by means of staybolts and on top by crown bars and radial stays which run to the outer shell. The back end above the tubes is supported by diagonal stays to the cylindrical shell of the boiler. The space at the sides of the furnace is called the water leg and in some cases, but not usually, this water space is carried beneath the fire box. On account of the small space between the water line and the boiler shell, it is usual to place a dome on the boiler, as the steam is thus much drier. This boiler requires no setting and is, therefore, well adapted for semi-, or portable use. It is often used in saw mills and for temporary installations on excavation work, and while not as economical as a boiler where a combustion chamber can be used, it gives fairly good economy, with cheap construction. It has a large amount of heating surface in proportion to the size of the boiler, and the power is, therefore, large for its weight and for the space occupied.

Ans. The boiler has a cone-shaped portion thus making the boiler of larger diameter at the furnace end than at the smoke stack end.

The object of this construction is to give more steam space, but the increase in size of boilers has raised the top so high above the rails that the wagon top is not now used as extensively as the straight top.

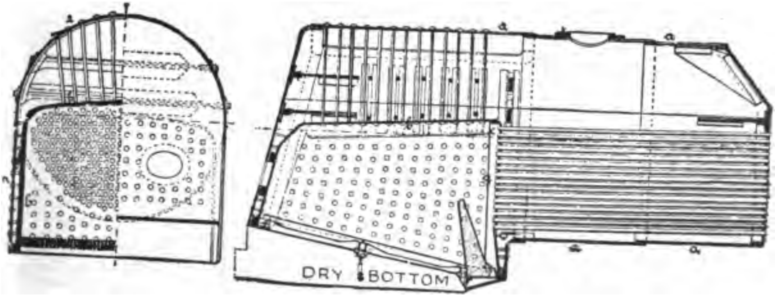
Ques. For what service are locomotive boilers sometimes used other than locomotive work?

Ans. Stationary and marine service.

Considerable additional matter on locomotive boilers will be found in chapter 37 on Locomotives.

Marine Boilers.—There is a multiplicity of types of marine boiler due to the great variety of steam propelled vessels, the large range of steam pressures and various kinds of fuel employed.

Stationary and locomotive boilers have been modified in design and used for marine service as well as the distinctively marine types.



FIGS. 3,639 and 3,640.—Marine type of locomotive boiler with dry bottom fire box.

Of the "borrowed types" the ***vertical*** or ***upright boiler*** finds its use on boats of smaller size. It has the advantages of taking up the least floor space and is cheapest in construction, and the faults of being the least efficient and having a high center of gravity.

There are, of course, vast differences in the various ways it is manufactured.

The locomotive boiler is advisable in marine work as a good steaming boiler with forced draught, and as having a low center of gravity, but has the objections of taking up too much room, fore and aft, and bringing the smoke stack too far forward.

The cylindrical return tubular boiler is the easiest boiler to keep clean, but on account of the limited grate area and diameter of furnace, not very efficient for the amount of metal used in its construction.

Where more than one furnace is used the efficiency rises, but even with three or four, it does not stand comparison with the square base boiler, taken pound for pound. It is by far the plainest and safest boiler, and can be made for a steam pressure of 200 pounds or more.

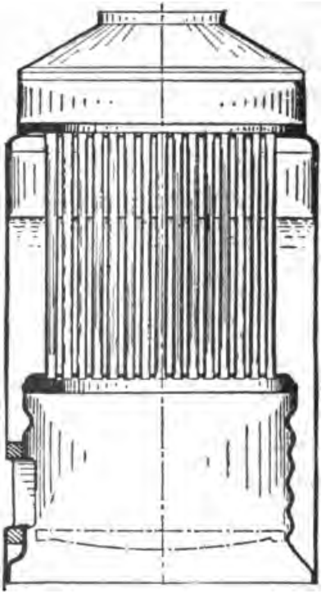
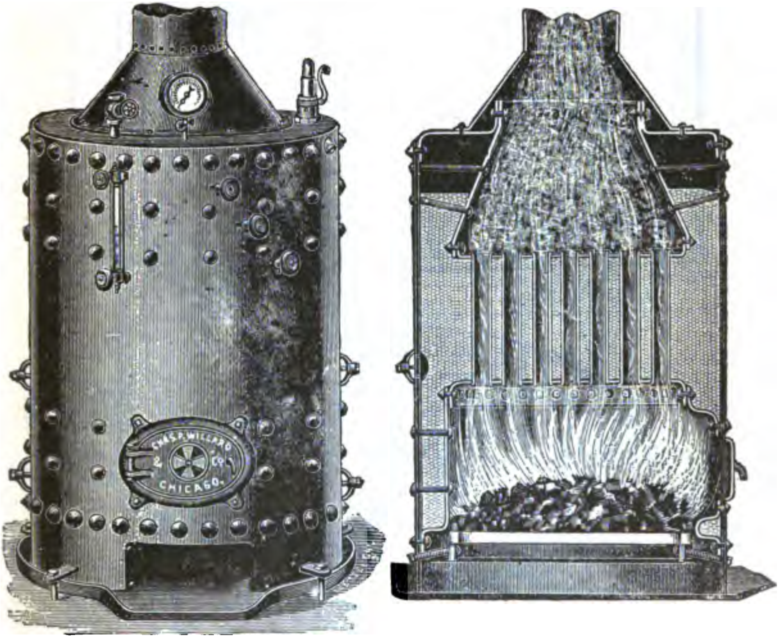


FIG. 3,641.—Through (sometimes called "flush"), tube vertical marine boiler. This boiler, if built of tested materials, is approved by the government inspectors, for use on all navigable waters of the United States, excepting on steamers navigating the Red river of the North and rivers whose water flow into the Gulf of Mexico *and all waters tributary to said waters*. This form of boiler is "borrowed" from the stationary type and by comparing it with fig. 3,631, it will be seen that its diameter has been increased and height lowered, also a much larger number of tubes are used, thus lowering the center of gravity and increasing the heating surface per pound weight—two features of importance for marine service. The type here shown has a corrugated furnace instead of the usual stayed construction.

Ques. What are the distinctive features of a Scotch boiler?

Ans. It is essentially a high pressure boiler, and has for this reason, most of the important members in cylindrical shape. They are all arranged horizontally. The gases pass to the back and are returned to the front for discharge

The important parts of a Scotch boiler are:

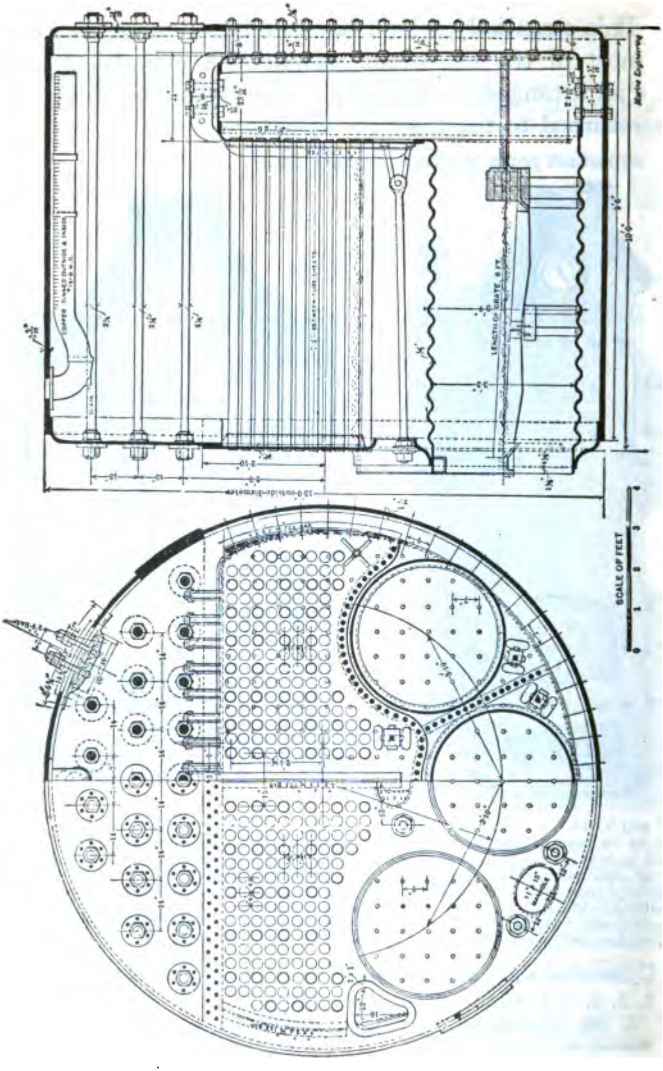

CHAS. P. WILLARD & CO. CHICAGO.

Figs. 3,642 and 3,643.— Chas. P. Willard submerged tube vertical marine boiler. Where boats are to be used in waters under U. S. marine supervision it will be necessary to have them built in every respect in conformity with U. S. marine laws. These require, among other things, that vertical boilers used on steamers navigating the Red river of the North, the Mississippi river and all rivers whose waters flow into the Gulf of Mexico, as well as all waters tributary to such rivers, ***must have submerged tubes***. This construction enables a boat to go into any waters, whereas, the through tube design, shown in fig. 3,641, is excluded from the waters just mentioned.

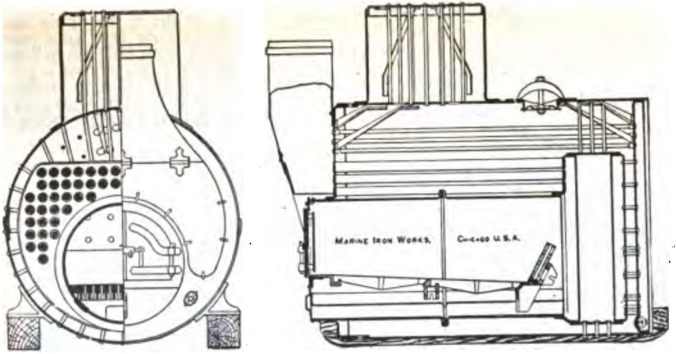
1. Cylindrical shell, which encloses the steam and water space.
2. 1, 2, 3, or 4 cylindrical furnaces that provide room for the grate.

   The grate divides the furnaces into the space for the gases above and into the ash pit below the grate.

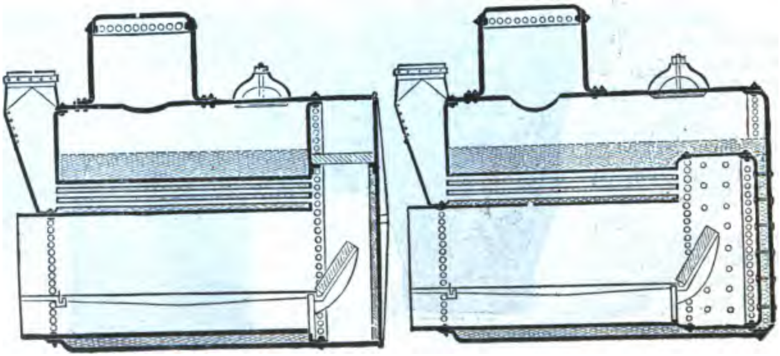
3. Tubes in large number, above and parallel to the furnaces. These



Figs. 3,644 and 3,645.—Modern high pressure, three furnace, single ended Scotch boiler showing construction and dimension of parts.



Figs 3,646 and 3,647.—Single furnace Scotch boiler as built by Marine Iron Works; sectional views showing general construction.



Figs. 3,648 and 3,649.—Clyde and Scotch boilers, showing distinctive feature of "dry" or removable water backs.

constitute the bulk of the heating surface and lead the gases to the uptake at the front of the boiler.

4. 1, 2 or 3 combustion chambers, or boxes for the combustion of the gases. They form the passages for the gases from the rear end of the furnace to the tubes.

They have flat tops, backs and tube plates and sides that require staying to resist the pressure of the steam.

5. Heads to close the ends of the cylindrical shell. These require staying to resist the steam pressure provided, partly by special bolts, partly by the tubes.

6. Uptake and funnel to carry off the burnt gases.

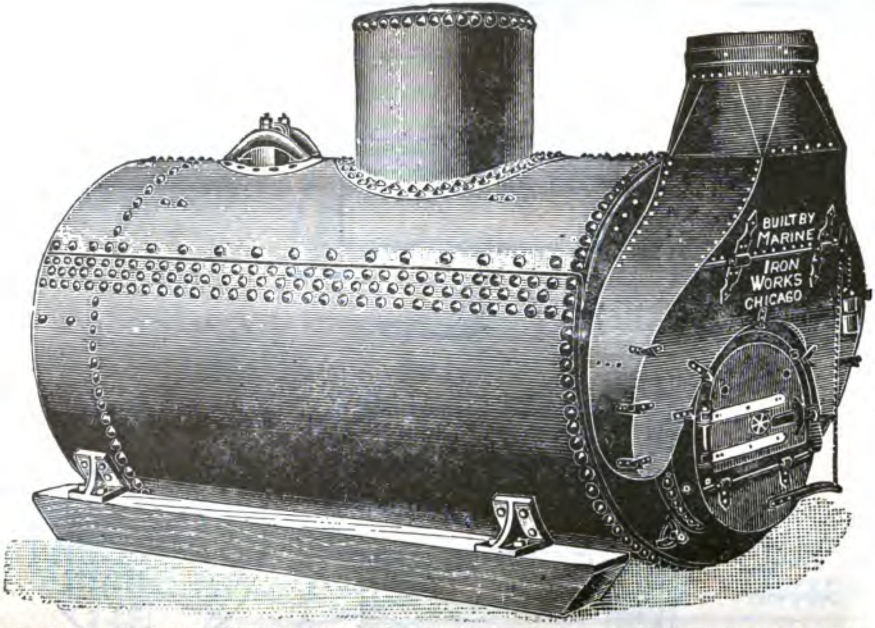


FIG. 3,650.—Marine Iron Works one furnace Clyde boiler showing its general appearance, and also that of the Scotch boiler. As shown, all surfaces of the fire box and shells are cylindrical adapting it to high pressure. The fire grate is placed in the large central flue thus surrounding the fire by water. When wood is used as fuel the grate is removed and the wood fed into the large furnace flue, it having been found in use that there is sufficient draught through the wood without the use of grates. The projecting metal work over the furnace door is the smoke bonnet or breeching which leads the gases (after exit from the tubes) to the stock. The tubes are at all times covered with water.

Figs. 3,644 and 3,645, show the construction of a three-furnace Scotch boiler.

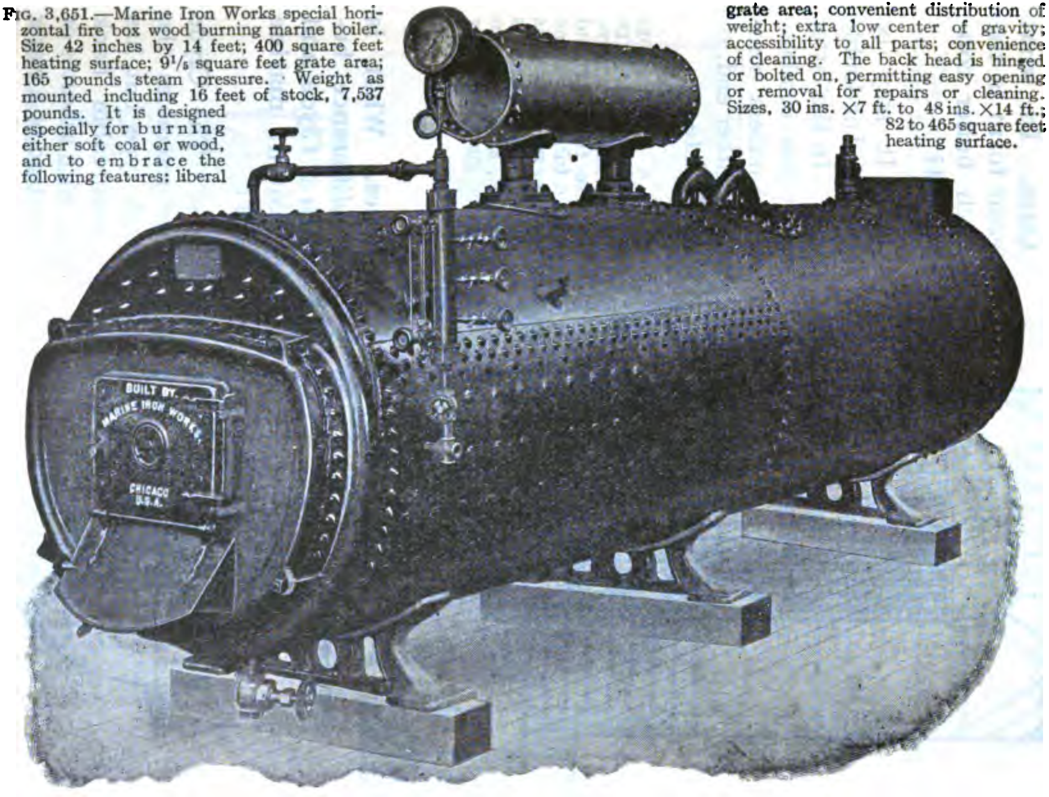
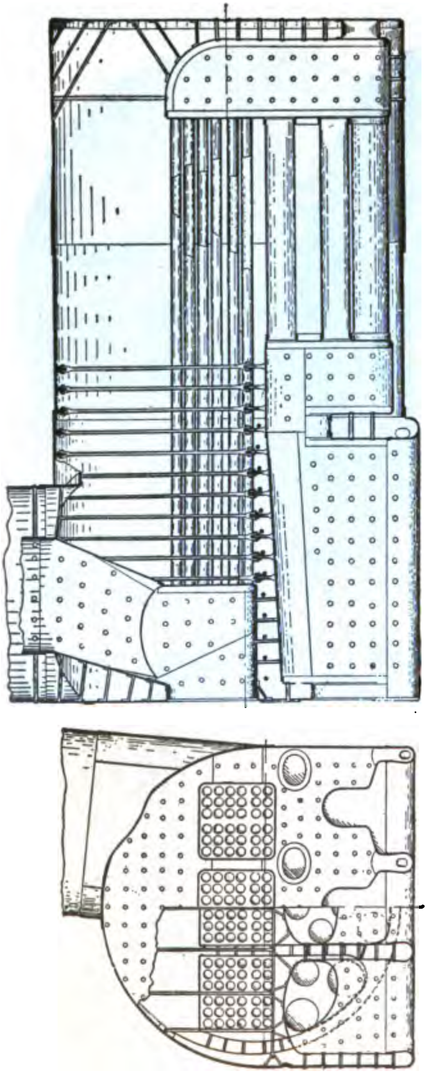


FIG. 3,651.—Marine Iron Works special horizontal fire box wood burning marine boiler. Size 42 inches by 14 feet; 400 square feet heating surface; $9^1/_5$ square feet grate area; 165 pounds steam pressure. Weight as mounted including 16 feet of stock, 7,537 pounds. It is designed especially for burning either soft coal or wood, and to embrace the following features: liberal **grate area**; convenient distribution of weight; extra low center of gravity; accessibility to all parts; convenience of cleaning. The back head is hinged or bolted on, permitting easy opening or removal for repairs or cleaning. Sizes, 30 ins. ×7 ft. to 48 ins. ×14 ft.; 82 to 465 square feet heating surface.



FIGS. 3,652 and 3,653.—Leg marine boiler showing the large flues leading from the furnace to the rear of the boiler and the (return) tubes leading to the front of the boiler, and part of superheater. The end view shows location of the furnaces, flues and tubes. This boiler has been extensively used on low pressure side wheel steamers.

Ques. In what special form is the Scotch boiler constructed?

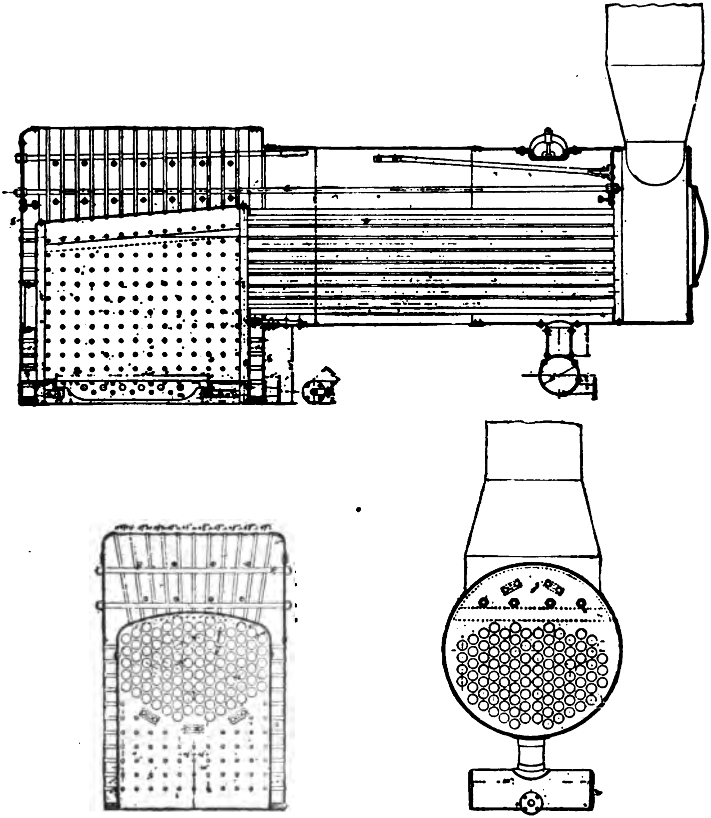
Ans. It may be single ended or double ended. In the latter case it has combustion chambers common to either end, or else separate.

As a usual thing, Scotch boilers are large in diameter to accommodate furnaces and return tubes all in one end; for special uses, as where head room is limited, a form known as the gun boat boiler is built.

Ques. What is the difference between a Clyde and a Scotch marine boiler?

Ans. The Clyde boiler resembles the Scotch type but has a removable back lined with asbestos or tile instead of a water space at the back end of the combustion chamber as shown in figs. 3,648 and 3,649.

When properly done this makes a satisfactory arrangement, as it makes the rear tube sheet very accessible for repairs and cleaning.



Figs. 3,654 to 3,656.—Rees locomotive type marine boiler with mud drum, low design for western river steamers. Fig. 3,654, longitudinal section; fig. 3,655, cross section through furnace; fig. 3,656, front end view with smoke door removed showing tubes.

Ques. What are the distinctive features of the leg, or flue and return tube boiler?

Ans. It is of cylindrical shape in that part of the shell containing the flues and tubes, while the one or more furnaces are similar to that in the locomotive boiler.

The one or more combustion chambers are similar to those of the Scotch boiler. The flues and tubes are arranged horizontally and the gases pass to the rear, being returned to the front into an uptake chamber, frequently built into the boiler. Around this uptake is often a vertical, cylindrical extension of the steam space, which acts as a super-heater and steam drier.

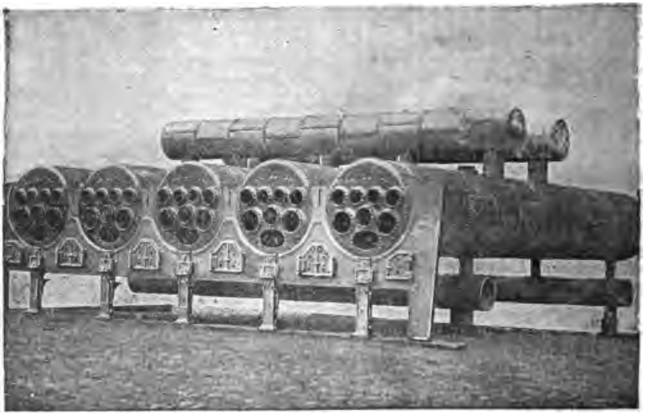


FIG. 3,657.—Rees western river type flue boiler.

The general construction is shown in figs. 3,652 and 3,653.

NOTE.—In the construction of very light draught Western river type boats, the plating after being shaped and placed is sometimes taken apart and galvanized for better preservation, and which process is found to considerably increase the life of the hull plating. The practice of James Rees & Sons Co. provides for double riveting to avoid leakage when in service, and which adds materially to the strength as well.

CHAPTER 65

WATER TUBE BOILERS

The essential difference between a water tube boiler and a shell or fire tube boiler is that the *water is* ***inside*** *the tubes instead of outside.*

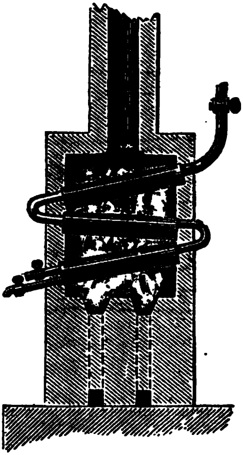


FIG. 3,658.—The first water tube boiler. Built by John Blakeley; patented 1766. ***It consisted of,*** three water pipes inclined alternately, connected at the ends by bent tubes so that the steam formed in the boiler rises to the upper part to supply the engine.

In this way, the water is divided into a large number of columns of small diameter, each entirely surrounded by heating surface, thus the generation of steam is very rapid.

The circulation is positive, being governed by the arrangement of the tubes, and the amount of water contained in the boiler is small as compared to the shell boiler of equal horse power. These features render the boiler very sensitive to changes in furnace and load conditions, that is, it has not so great reserve capacity as the shell types, and while steam can be raised quickly, a sudden call for power will often result in a temporary drop in pressure, while if the load be suddenly removed, the pressure will quickly rise and the safety valve blow before the fires can be checked.

Types of Water Tube Boilers.—There is a great variety of water

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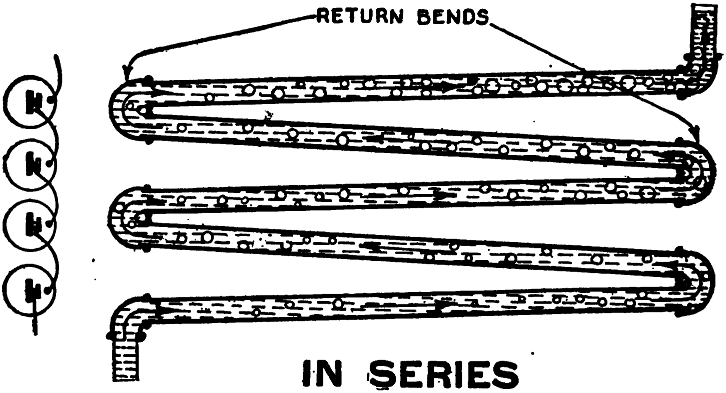
NOTE.—The term ***tube***, is here (because of common usage) loosely used. It should be understood that the heating surface may be composed either of tubes expanded into headers, or ***pipes***, with threaded ends.

tube boilers adapting them to any kind of service—stationary, locomotive, and marine.

A classification to be comprehensive should group the boilers with respect to several points of view. Accordingly, water tube boilers may be classed:

1. With respect to the grouping of the tubes, as
   - *a.* Non-sectional.
   - *b.* Sectional.



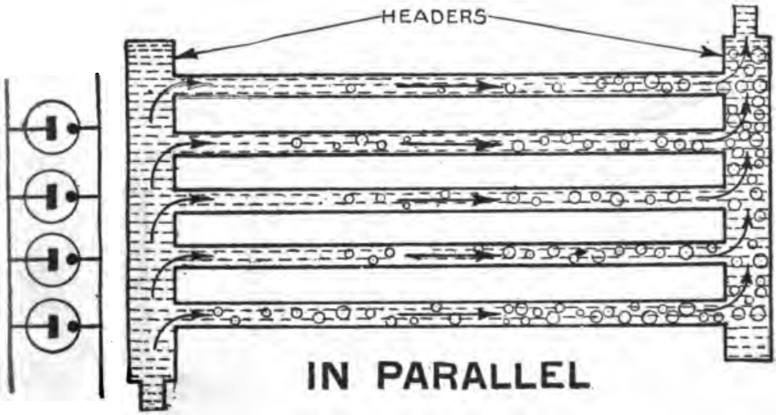
Figs. 3,659 and 3,660.—***Series connection,*** showing electric dry cells connected *in series* and arrangement of pipes joined by return bends.

2. With respect to the heating surface, as
   - *a.* Tube.
   - *b.* Pipe.

3. With respect to the shape of the tubes or pipes
   - *a.* Straight.
   - *b.* Curved.
   - *c.* Coiled.
   - *d.* Closed (porcupine).

4. With respect to the arrangement or assembly of the heating surface, as

- *a.* All in series.*
- *b.* All in parallel.*
- *c.* Sections in series.
- *d.* Sections in parallel.
- *e.* Sections in series parallel.



FIGS. 3,661 and 3,662.—***Parallel connection,*** showing electric dry cells connected ***in parallel,*** and similar arrangement of tubes expanded into two headers.

5. With respect to position of the tubes, as

- *a.* Horizontal.
- *b.* Inclined.
- *c.* Vertical.

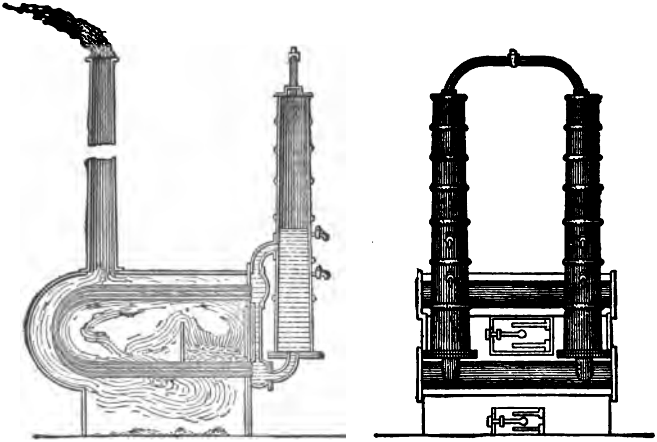
6. With respect to circulation features, as

NOTE.—The terms ***series*** and ***parallel*** are here used with their electrical significance, that is, just as a number of electric cells are connected up to form a battery, a number of pipe lengths joined end to end like the links of a chain are connected *in series*; if they be joined to two headers so that as many separate paths are presented for the flow of the water as there are pipes they are said to be connected *in parallel*, as shown in figs. 3,661 and 3,662.

- *a.* Up flow.
- *b.* Down flow.
- *c.* Over discharge (priming tube).
- *d.* Under discharge (drowned tube).
- *e.* Directed flow (double tube).

7. With respect to combustion features

- *a.* Direct draught.
- *b.* Baffled draught.
- *c.* Down draught.
- *d.* Water tube grate

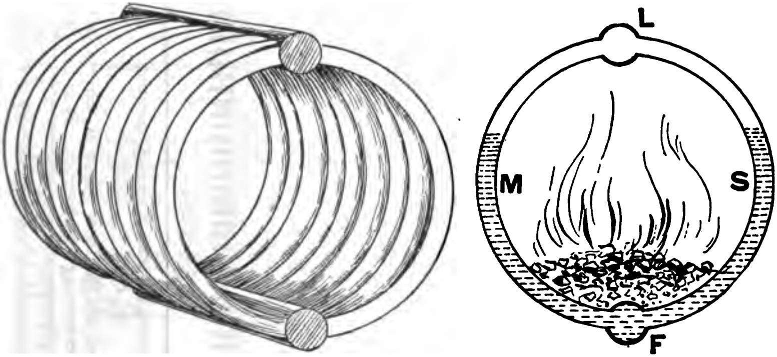


FIGS. 3,663 and 3,664.—Gurney's boiler as improved by Dance (1826) showing water grate. ***In construction,*** a number of U shape tubes were laid sidewise and the ends connected to larger horizontal pipes. These were connected by vertical pipes to permit circulation and also to vertical cylinders which served as a steam and water reservoir.

Clearly other divisions may be added, as for instance, with respect to the kind of furnace, jacket, etc., but the above is ample for a general consideration of the subject.

Essential Parts.—Any water tube boiler, no matter how complex may be its construction, is made up of the following principal members:

1. Steam and water drum.
2. Down flow tubes.
3. Up flow tubes.
4. Mud drum (or header).
5. Feed water heater.
6. Super-heater.
7. Grate.



FIGS. 3,665 and 3,666.—W. H. James' water tube water grate boiler. ***In construction,*** it consisted of small circular tubes MS, inserted into large pipes L, F, as shown. The feed pipe F, distributes the water uniformly to the circular upflow elements, steam being collected in the top pipe L. The boiler was 24 inches in diameter. James patented this boiler in 1825 and may be considered as the first inventor who practically understood what was required to constitute an efficient boiler.

These are assembled together into one unit by means of suitable fittings and connections, and the assembly placed in an insulating casing containing the furnace.

Elementary Water Tube Boiler.—The various parts comprising a water tube boiler, as just mentioned are shown assembled in the elementary diagram fig. 3,667.

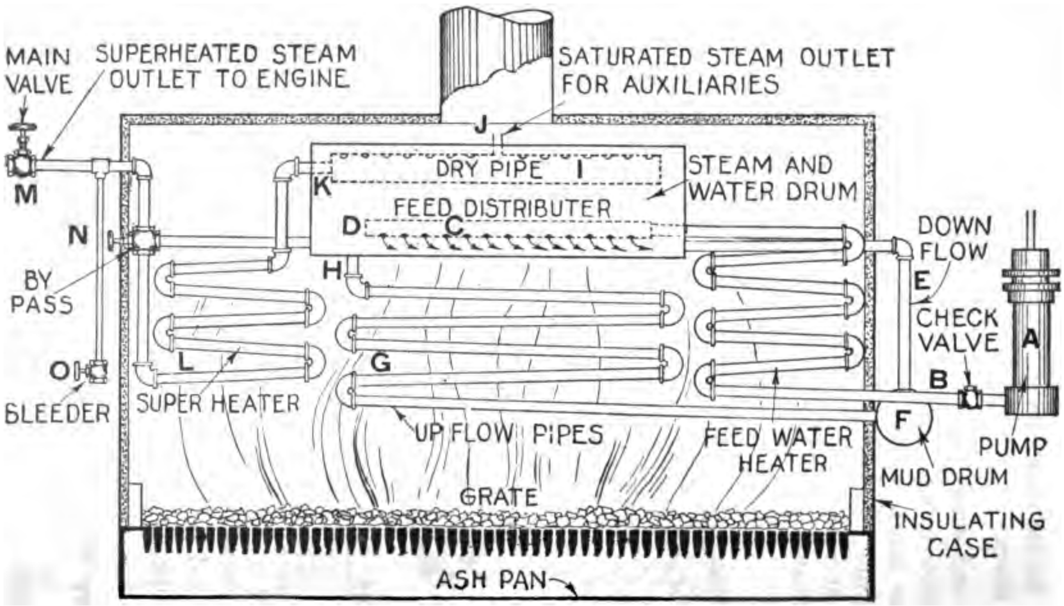


Fig. 3,667.—Elementary water tube boiler, showing essential parts and operation.

In operation feed water discharged by the feed pump A, enters the feed water heater at B, and is raised usually to the boiling point in traversing the heater. It is discharged into the drum through the feed distributer C, with minimum disturbance.

The ideal feed is constant and regulated to correspond with the steam demand.

The water in the drum D, and down flow pipe E, which is not as hot as that in the up flow pipes, and therefore denser or heavier, flows by virtue of its excess weight downward through the down flow pipe to the mud drum F, thence through the up flow tubes, entering the drum again at H.

As the water traverses the up flow tubes a multiplicity of steam globules are formed thus greatly increasing the inequality in weight of the ascending stream in the up flow tubes and the descending stream in the down flow pipe, hence ***a rapid circulation is produced*** as indicated by the arrows. Because of this rapid circulation, any impurities in the water are deposited by centrifugal force in the bottom of the mud drum. This force is made available by suddenly changing the direction of flow at the mud drum.

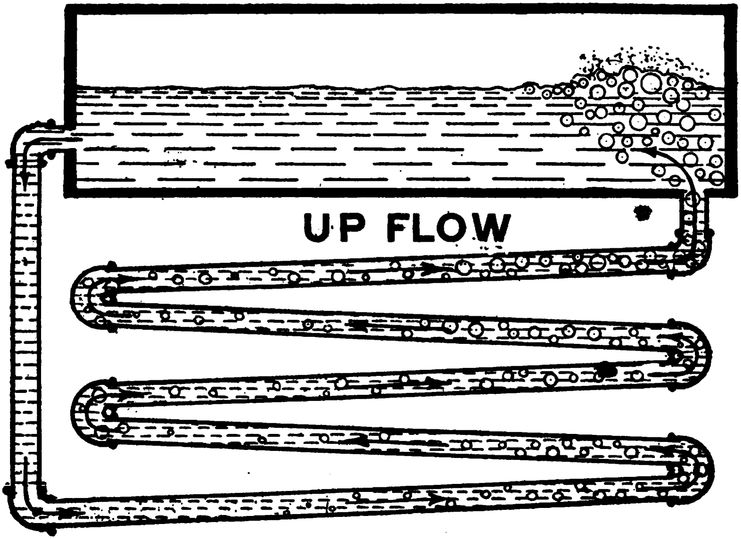


FIG. 3,668.—***Circulation principles:*** 1, illustrating up flow.

With scale forming waters, a considerable deposit takes place in the feed water heater section of the boiler, sometimes these tubes become almost entirely choked up with scale, necessitating renewal.

At the top of the drum is a dry pipe I, by means of which steam is drawn from the drum along its entire length rather than in one spot, thus priming is reduced to a minimum.

There are two outlets to the dry pipe: one J, direct, and the other K, connected to the super-heater L, which terminates at the main outlet M, of the boiler.

Steam, in passing from the dry pipe, is super-heated to any degree required as governed by the size and position of the super-heater.

The super-heater being exposed to the hot gases from the furnace, becomes very hot when there is no demand for steam, dangerously so in some types, and to prevent overheating, a by pass N, is sometimes arranged, as shown. so that water mav be admitted from the drum and the super-heater flooded when the main valve is closed. The super-heater is cleared of water on resuming operation by means of a *bleeder* O.

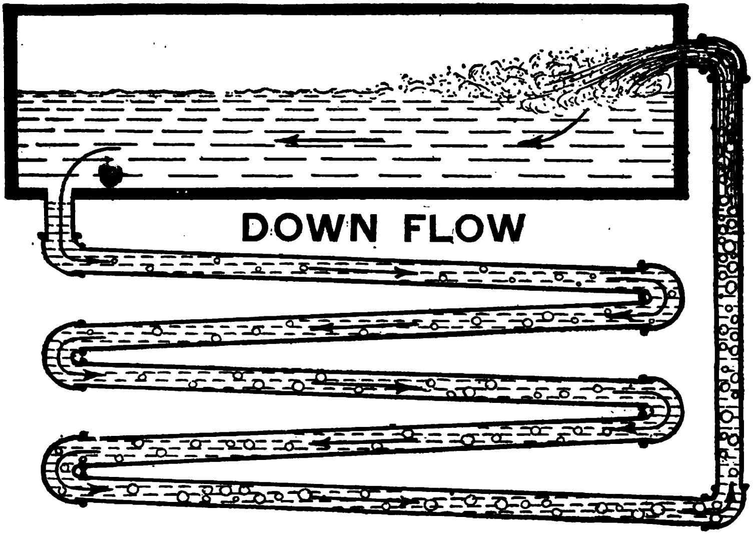
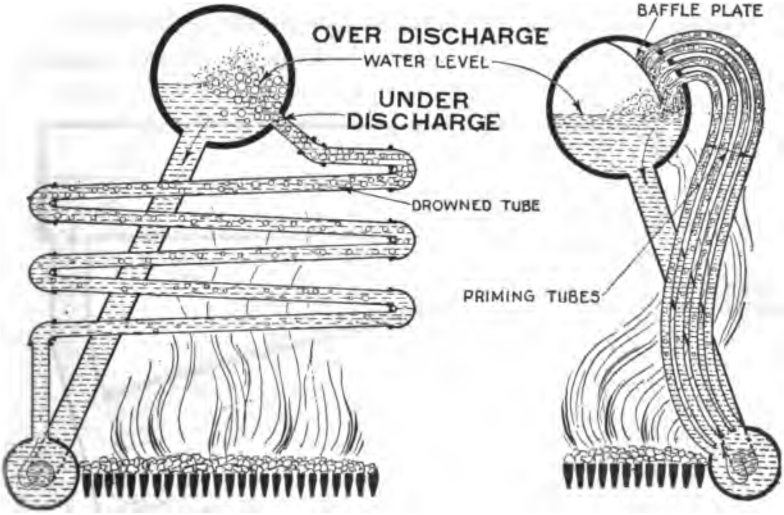


FIG. 3,669.—***Circulation principles;*** **2, illustrating down flow.**

In the diagram (fig. 3,667), the parts are so arranged that all are visible for clearness, but in practice the elements comprising the boiler are arranged so that each is placed in such a position relative to the furnace as experience shows is best, and that will give a compact assembly.

Non-Sectional Boilers.—This type of boiler consists essentially of a mass of tubes expanded in *parallel* to two headers which connect with the ends of the drum, as in fig. 3,673. There are many arrangements, for instance, a transverse drum may



FIGS. 3,670 and 3,671.—***Circulation principles:*** III, illustrating ***under discharge*** (drowned tube), and *over discharge* (priming tube). In the latter method a baffle plate is necessary tc protect the outlet from spray especially in the absence of a dry pipe.

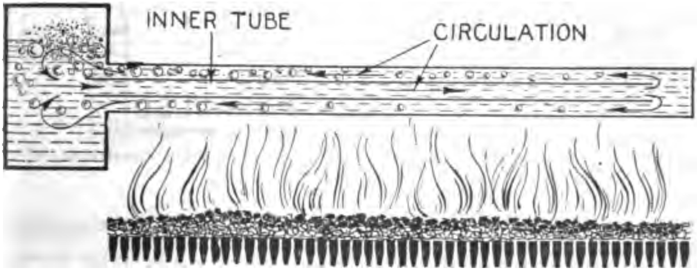


FIG. 3,672.—***Circulation principles:*** IV, illustrating *directed flow* (due to Field). In the Field drop tube and sometimes in the so called "porcupine" type boiler the heating surface is composed of tubes closed at one end and the circulation "directed" by means of a smaller inner tube through which the relatively cold water flows and returns through the larger tube as shown.

be used attached longitudinally to one header (as in the Ward boiler) and return tubes leading back for the other header shown in diagram fig. 3,674.

Ques. What are the advantages of these boilers?

Ans. Since all the tubes are accessible for internal cleaning, they may be used with waters of such degree of impurity as would preclude the use of other types. Straight tubes are more easily obtained than the curved variety.

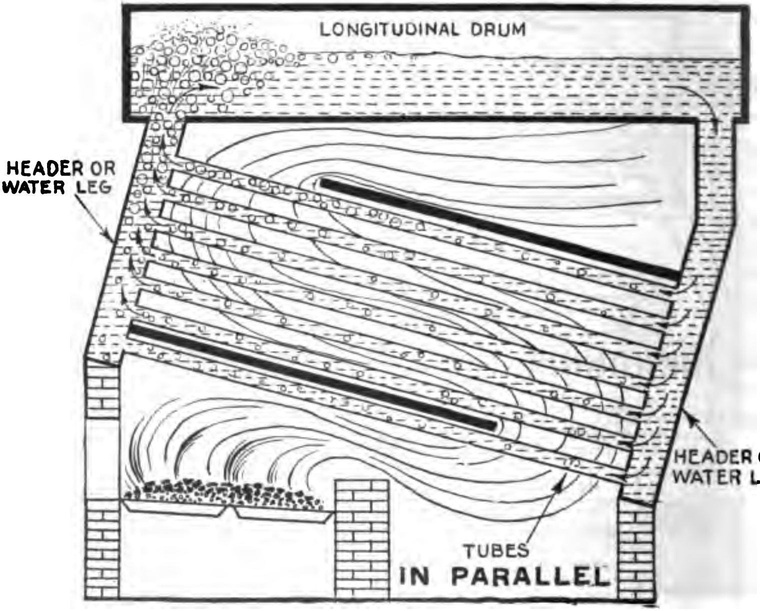


FIG. 3,673.—Elementary non-sectional boiler with longitudinal drum *consisting of drum, two headers or water legs and mass of tubes in parallel.*

Sectional Boilers.—Instead of connecting all the heating surface in parallel to two headers as in the non-sectional boiler, it is sometimes divided into a number of sections or units each consisting of 1, a few tubes expanded in parallel to small headers, or 2, a few pipes joined in series by return bends. Each of these sections is joined to a manifold or common passage leading to the drum. The essential features of each type are shown in the elementary diagrams, figures 3,675 and 3,676.

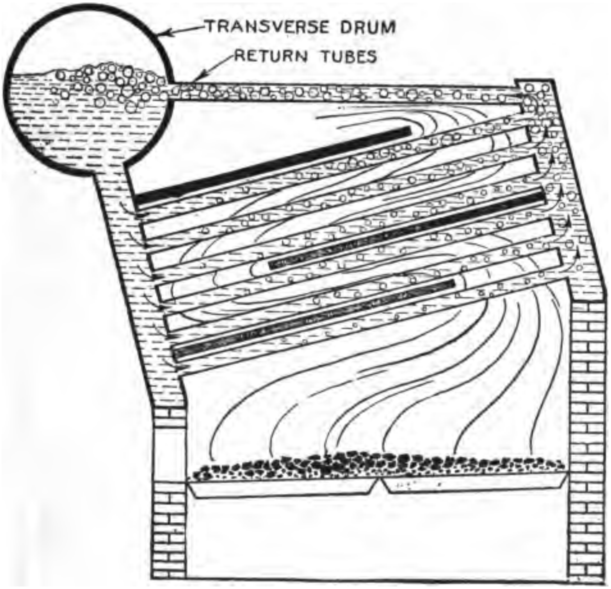


FIG. 3,674.—Elementary non-sectional boiler with transverse drum, and return tubes. Since only one header is connected to the drum evidently some means of completing the path for circulation must be provided, hence the return tubes.

Ques. Mention an important point that should be noted with respect to boiler tubes in parallel and in series.

Ans. In the parallel arrangement all the tubes are accessible for cleaning adapting the boiler to the use of impure feed water,

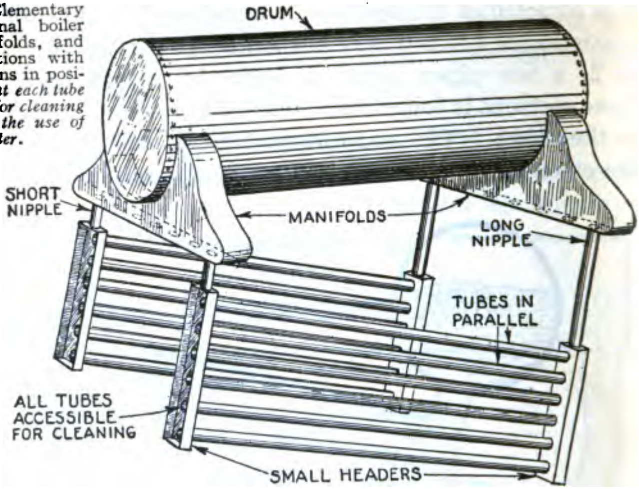


Fig. 3,675.—Elementary parallel sectional boiler showing manifolds, and two tube sections with their connections in position. *Note that each tube is accessible for cleaning which permits the use of impure feed water.*

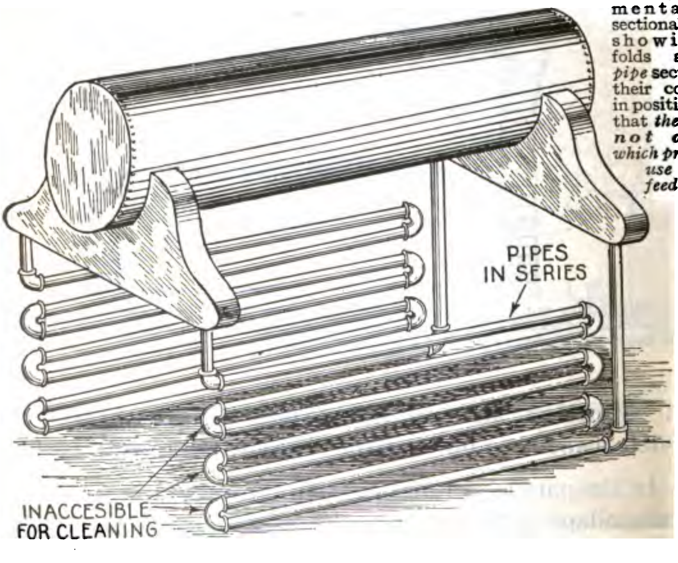
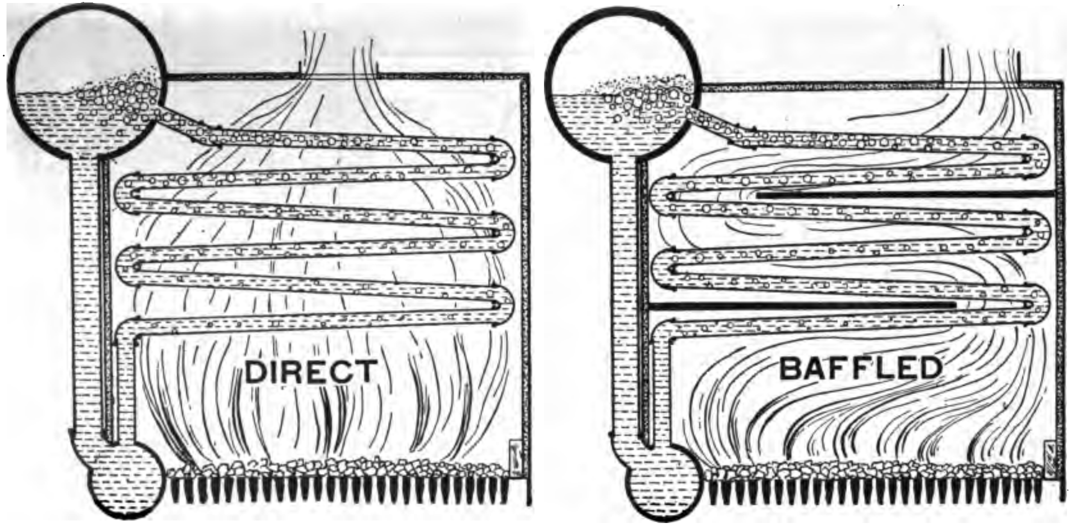


Fig. 3,676.—Elementary series sectional boiler showing manifolds and two *pipe* sections with their connections in position. Note that *the pipes are not accessible which precludes the use of impure feed water.*



FIGS. 3,677 and 3,678.—***Combustion principles,*** illustrating direct draught and baffled draught. Evidently with direct draught there is more or less short circuiting of the hot gases rendering portions of the heating surface correspondingly less effective, on the other hand, baffles, especially of the horizontal type here shown become, in time, coated with accumulation of ashes, etc., necessitating frequent cleaning.

whereas the inaccessible series arrangement precludes the use of impure feed water.

Ques. What advantages have sectional over non-sectional boilers?

Ans. The sectional boiler can be more easily transported than the non-sectional type over difficult routes because it can be knocked down into a number of comparative light units. The sectional construction avoids the use of stay bolts.

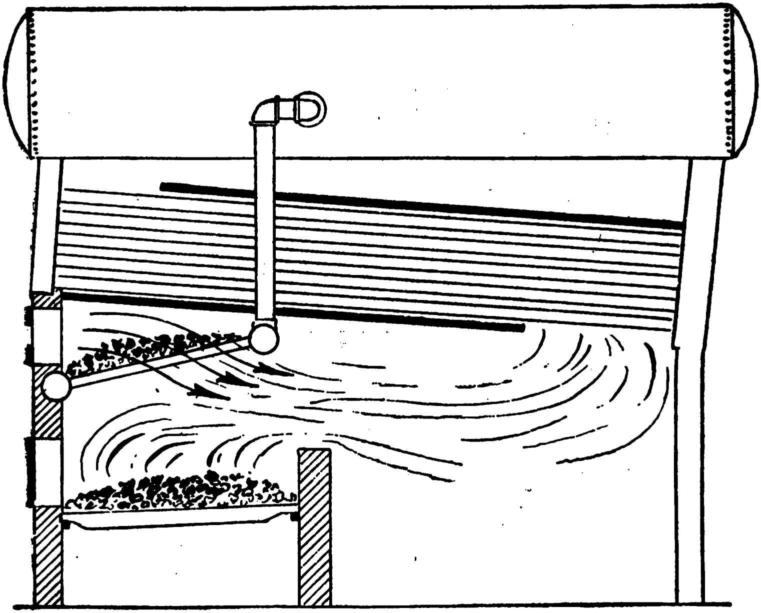


FIG. 3,679—***Combustion principles,*** illustrating down draught. Here, coal is placed on a supplementary furnace, and air admitted from the top. ***In operation,*** the cold air and cool distilled gases pass together down through the hot coke, and if the air supply be sufficient the gases will be thoroughly burned and smoke will be prevented. To prevent the burning out of the grate bars they are made of water tubes, forming part of the heating surface of the boiler.

Pipe Boilers.—Ordinary wrought iron pipe and malleable fittings, are extensively used in water tube boiler construction, being adapted especially to the sectional series arrangement.

NOTE.—In the selection of a Pipe Boiler, points to be noted are: 1, Accessibility for repairs especially the location of the *r* and *l* connections which have to be reached to remove sections; 2, special fittings (these are preferably avoided in design, especially for boilers used in remote places because of delay in sending to factory for new parts in case of repairs; 3, provision for cleaning; 4, construction of casing; 5, mud drum and blow off; 6, lifting ring for connection to hoist tackle in installing.

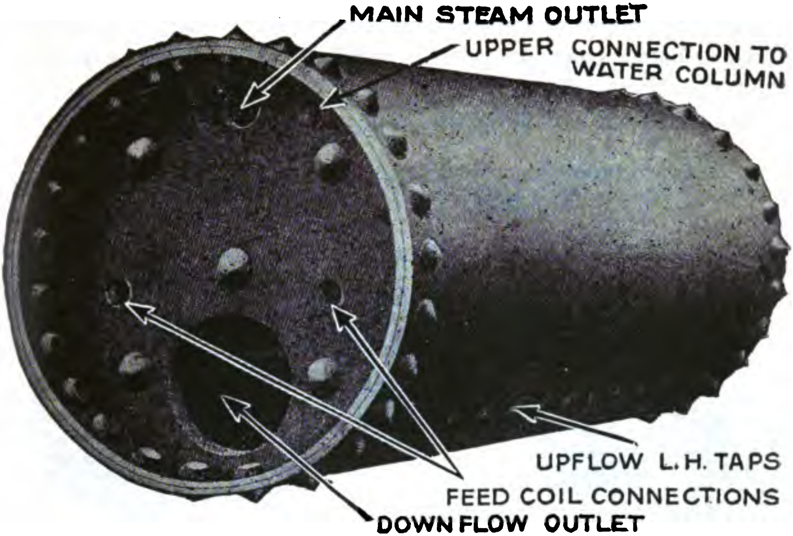


FIG. 3,860.—***Roberts water tube boiler construction:*** 1, *steam drum*. The drum is constructed of open hearth steel and the heads riveted in and reinforced by through braces, as shown. The upper small hole is the top connection for the water column and the lower ones connect to the feed coils.

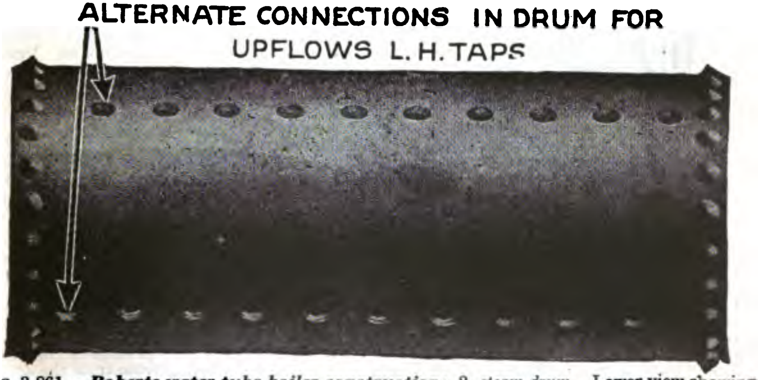


FIG. 3,861.—***Roberts water tube boiler construction:*** 2, *steam drum*. Lower view showing two longitudinal rows of holes tapped for connecting *nipples* to *up flow coils*. These holes are spaced alternately for alternate connection with coils leading to the right and left *side pipes*.

The pipe used is made in sizes according to the Briggs standard and are listed according to the nominal inside diameter rather than the actual diameter, there being considerable difference, especially in the smaller sizes.

The Briggs thread is a taper thread and a tight joint is made by screwing the pipe into the fitting until a very firm connection is secured.

One of the earliest and at present prominent make of pipe boiler is the Roberts, which is a good example of pipe boiler.

It is built up in sections, each section being composed of a few lengths of pipe connected in series by return bends. The lower end of each section is connected by a right and left long nipple to a bottom header or side pipe, and the upper end by a short right and left nipple to the drum as shown in fig. 3,684 the left handed thread connection being in the side pipe and drum. The figure shows two sections in position and the large connecting pipes between the side pipes and drum, the assembling of connecting or down

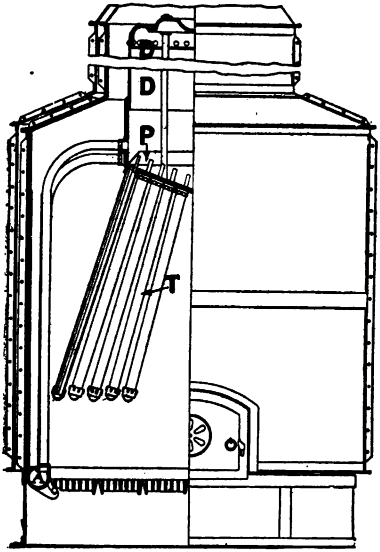


Fig. 3,682.—Ward Field or double drop tube boiler (round type). D, is a circular drum into which the "downcomers" are tapped. Into the conical bottom of the drum D, a number of straight Field tubes are secured, the ends being closed by caps, and the inner ends by tight fitting plugs in which are two small holes. Into each hole is fitted a small brass tube open at both ends, one tube extending inside of the hanging tube to within an inch of the bottom, and the other and shorter one projecting about 4 inches into the drum. Around the inside of the drum, an inclined diaphragm P, is fitted below the openings of the lower row of vertical tubes. This diaphragm separates the main generating tubes from the downcomers. By means of the internal feed pipe not shown, the feed water is delivered to the lower row of tubes, going thence to the manifold and returning to the drum by the tubes that enter highest. From the drum the water goes down the long brass tube inside T, where steam is formed which returns to drum through the short brass tube.

flow pipes and side pipes also serves as a frame which holds the part rigid in position.

Fig. 3,685 shows boiler complete without case. As shown the two pipe sections on either side of the drum form the feed water heater, being connected in parallel series. The superheater consists of two sections located on the sides and extending down to the fire brick.

Ques. What are the features of pipe boilers?

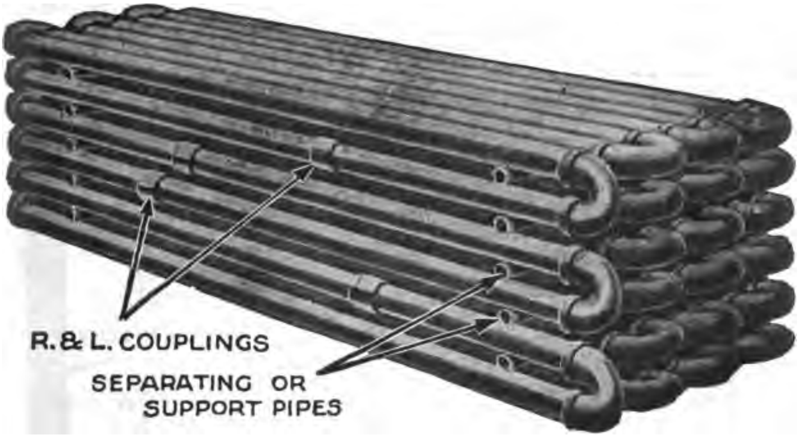


FIG. 3,683.—***Roberts water tube boiler construction:*** 4, *feed coils*. There are two, one on each side of the drum (as shown in fig. 3,685). The feed pipe from the pumps or injector passes through the jacket about on a level with the center of the drum head and enters the *feed tee* which connects the feed coils *in parallel* entering each at the top, the feed water traveling each horizontal layer of pipes progressively from top to bottom of the coils, where it is delivered into the drum through the *discharge feed tee above the water line*. It is delivered ***above*** the water line to permit any steam which may form in the coil to rise to the top of the drum and the water to fall to the water level. The down flow of water through the coils results in a nearer constant temperature difference between the temperature of the water and that of the hot gases, than would be the case if the feed entered the lower layer and flowed upward. Both coils deliver into the head of the drum. The cross pipes are *spacers*, to prevent obstruction of the draught. Although these *spacers* have no water in them they last for years in practice.

Ans. The material of which they are constructed is cheap and easily obtained anywhere in case of repairs. They can be shipped knocked down, facilitating transportation over difficult routes, and are easily assembled by any pipe fitter of ordinary intelligence; high steam pressure may be safely carried.

Ques. Where are pipe boilers largely used?

Ans. In marine service.

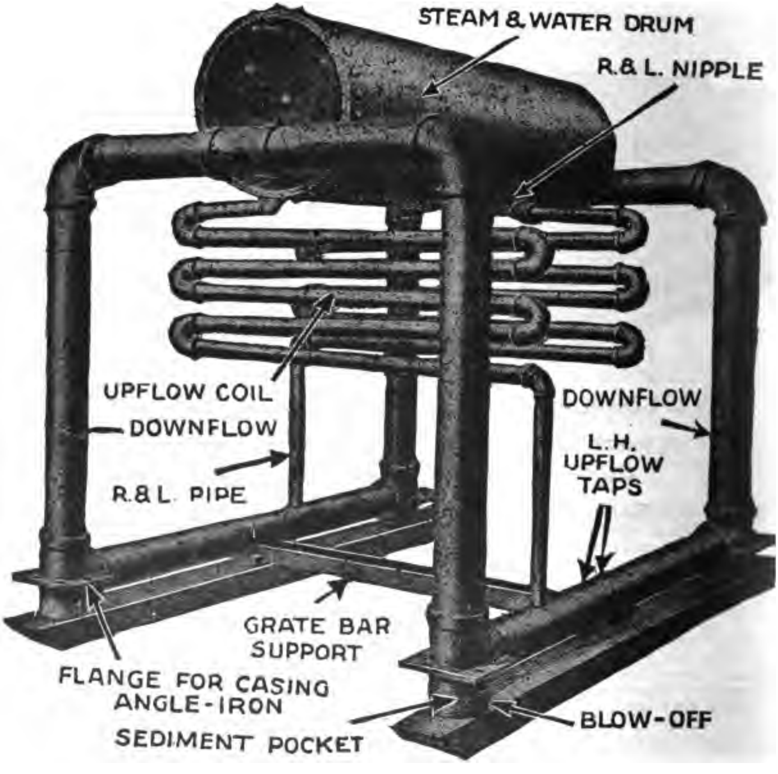


FIG. 3,684.—***Roberts water tube boiler construction:*** *5, boiler* ***in frame with two up flow coils and bearing bars*** *(for grate) in position.* The holes in the drum and side pipes have left hand threads, and the coils being connected by *r* and *l* nipples any coil may be removed without disturbing the others. In all boilers over 6 feet in width, these up flow coils only run to center, the opposite coils meeting same in the center of the boiler.

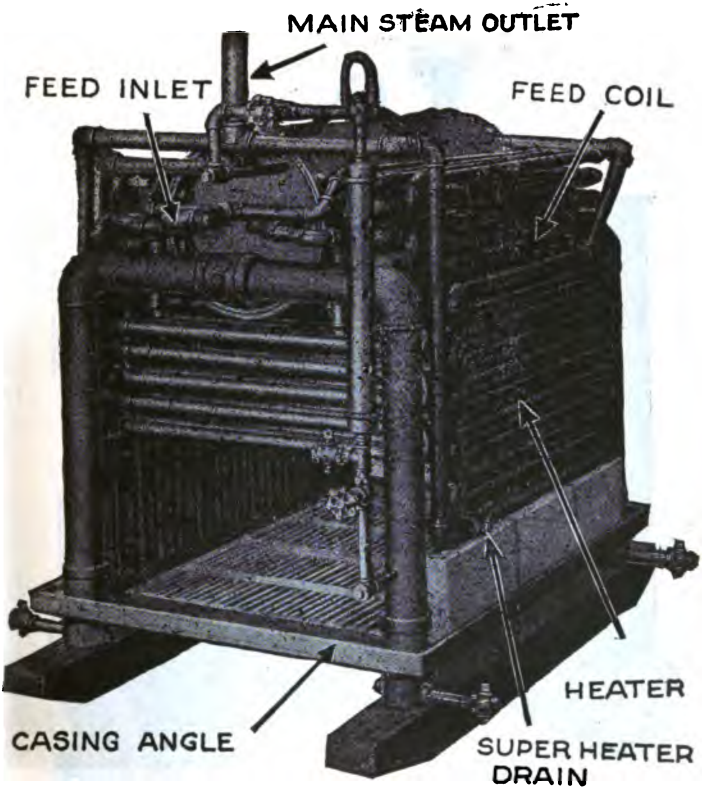


FIG. 3,685.—***Roberts water tube boiler construction:* 6, *boiler complete except jacket or casing.*** The angular pipe at the upper rear end leads from the dry pipe, inside the drum, through the superheater coil (marked "heater" in above illustration); thence through the riser at the front to a bull head tee (in front of the drum) which is the main steam exit and connects also with the other superheater coil which is on the opposite side of the boiler similar to the one explained, except it takes the steam from the dry pipe at the front end of the boiler. The fire brick shown on the sides are not so thick but that they leave sufficient room for the jacket to enter the angle iron. They are also hollow for lightness, weighing about ⅓ as much as ordinary fire brick of equal size. The tee projecting in front of the drum head is the feed water inlet. The water column is connected by *r* and *l* nipples. The lowest portion of the down flow pipes are small pockets, each being provided with a blow off valve as shown.

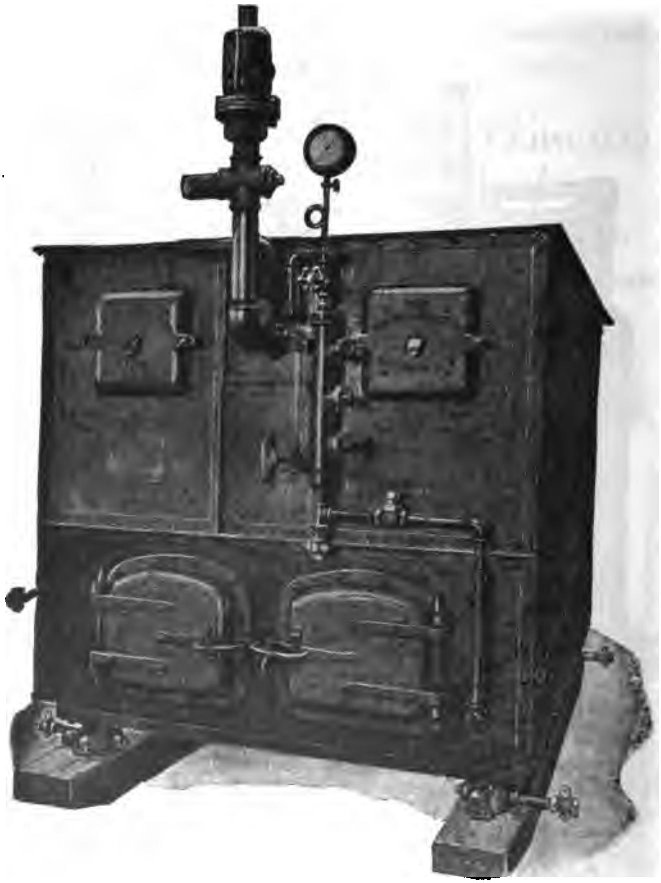
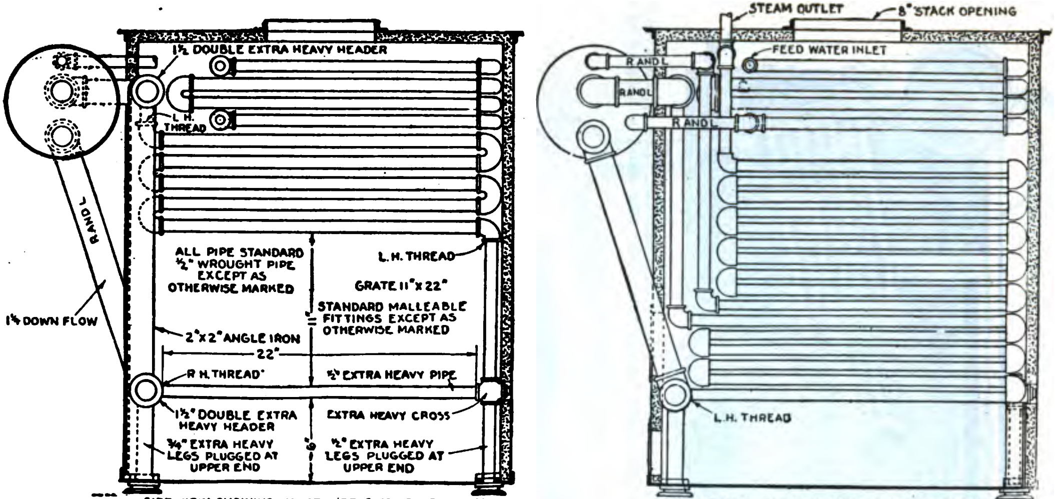


Fig. 3,686.—***Roberts water tube boiler construction: 7, complete boiler with double jacket or casing,*** showing main steam outlet, safety valve, water column cleaning doors, etc. Every section of the jacket is filled in with magnesia or asbestos 1½ inches thick. The vertical rows of tap bolts at each edge of the front are tapped into the ends of the side sections; the back section is fastened in the same way. By taking out these bolts after removing the top, the front and back and two sides may be lifted out. The circulation of the Roberts Boiler is claimed to be perfect and very rapid, the boiler being so designed that the hottest waters come in contact with the hottest gases and the tail end gases come in contact with the cold water in the feed coils, resulting in low stack temperatures and very economical as to fuel.


1½ DOUBLE EXTRA HEAVY HEADER
L.H. THREAD
R AND L
1¼ DOWN FLOW
ALL PIPE STANDARD ½" WROUGHT PIPE EXCEPT AS OTHERWISE MARKED
L.H. THREAD
GRATE 11"x 22"
STANDARD MALLEABLE FITTINGS EXCEPT AS OTHERWISE MARKED
2"x2" ANGLE IRON
22"
R H. THREAD
½" EXTRA HEAVY PIPE
1½" DOUBLE EXTRA HEAVY HEADER
EXTRA HEAVY CROSS
¾" EXTRA HEAVY LEGS PLUGGED AT UPPER END
6"
½" EXTRA HEAVY LEGS PLUGGED AT UPPER END
STEAM OUTLET
8" STACK OPENING
FEED WATER INLET
R AND L
R AND L
R AND L
L.H. THREAD

SIDF VIEW SHOWING INNER UPFLOWS, FEED WATER HEATER COILS, ETC.

SIDE VIEW SHOWING OUTER UPFLOWS, SUPERHEATER, FEED WATER HEATER COILS, DRUM CONNECTIONS AND SUPPORTING LEGS

Figs. 3,687 and 3,688.—Two side views of small sectional series pipe boiler designed by **the author to furnish steam** for experimental purposes; now under construction. The features of this design are case and cheapness of construction, water grate and furnace enclosed on three sides by water heating surface. It can be made up entirely of pipe and fittings, though a lighter drum may be made by the use of a large tube with heads turned out of boiler plate and properly stayed. The sections are made up of ½-inch pipe and return bends with *r*, and *l*, elbows at the lower ends and are connected to upper heads by *r*, and *l*, nipples. There are 10 up flow sections, 8 inner sections as shown in fig. 3,687, and two side sections as shown in fig. 3,688. There are two super heater sections, one on each side (fig. 3,688). ***Proportions:*** Up flows 26.6 square feet; feed water heater 13.3 square feet; super heater 7.1 square feet; total heating surface 47 square feet; total length ½-inch pipe 212 feet; grate area 1.92 square feet; ratio 1:25.4. Grate is made of extra heavy ½-inch pipe spaced 1⅜ inches between centers. The case indicated in dotted lines is made of thin sheets iron lined with asbestos board.

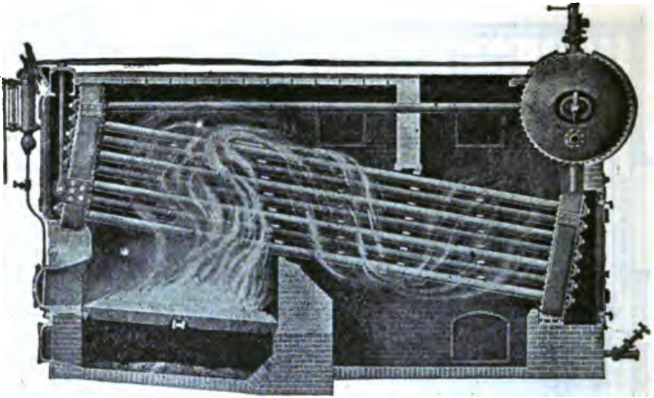


Fig. 3,689.—Keeler non-sectional transverse drum horizontal boiler. This type was developed to meet the demand for a high pressure water tube boiler that could be installed in boiler

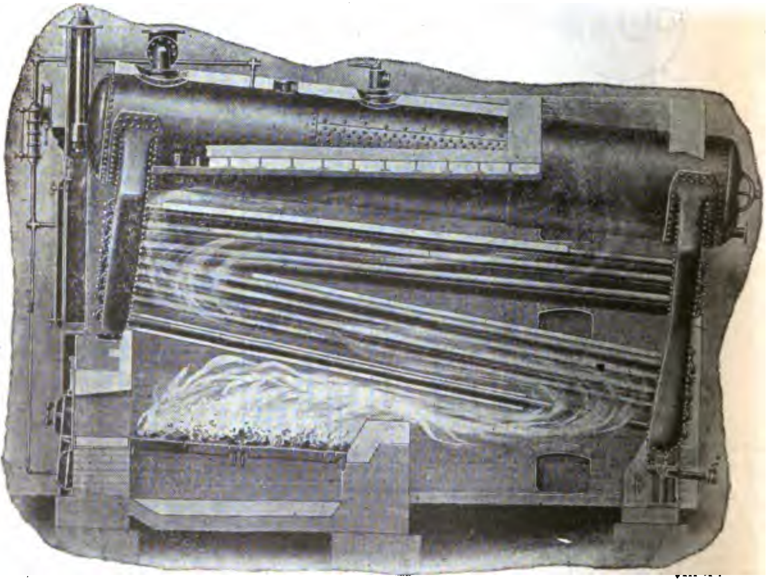


Fig. 3,690.—Casey-Hedges non-sectional horizontal boiler. The baffles are so arranged that there are two passes of the hot gases through the tubes and can be adjusted to draught

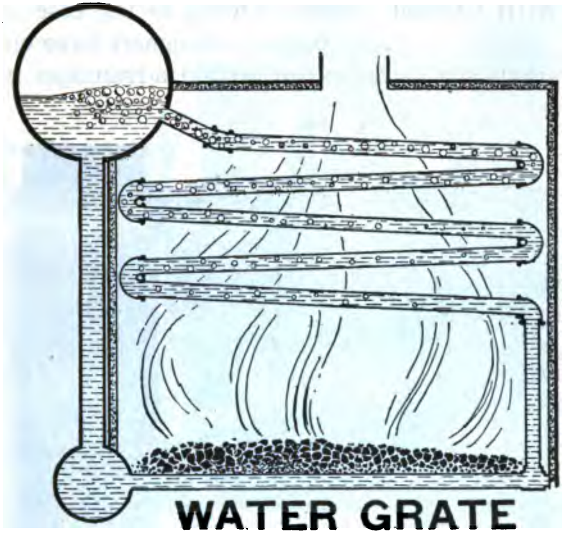


FIG. 3,691.—"Water grate." ***It consists of*** a series of pipes connected close together ***in parallel*** to a header at one end and to the up flow elements at the other, thus avoiding sagging or burning out as experienced with ordinary grates especially when forced. In early times water grates were tried out by James, see figs. 3,665 and 3,666, Gurney and others. **Figs. 3,687 and 3,688 show small boiler with water grate as designed by the author and now under construction.**

FIG. 3,689.—*Text Continued.*

rooms where ceiling height is limited or where the boiler must be introduced through narrow passageways or restricted openings. The pressure parts of the boiler are shipped in a knocked down condition, making it possible to install it without cutting through walls and floors in locations that would be wholly inaccessible for almost any other type of boiler. For export the cross drum boiler can be handled at much less expense by steamship companies on account of its reduced bulk in a knocked down condition, and the comparatively small weight of the heaviest piece; this feature adapts it to remote places where it must be transported over difficult roads, weak bridges, etc.

FIG. 3,690.—*Text Continued.*

conditions. The lower row of tubes is completely encased with tile, which forms an incandescent reverberatory roof over the furnace, converting it into a Dutch Oven. The tubes are divided into two banks, an upper and lower bank. The lower bank is inclined two inches to the foot. The lower bank of the tubes being the hottest, in consequence the circulation is most rapid, therefore, the necessity of the increased inclination. The upper row of tubes and drum are inclined one inch to the foot. The boiler is supported at the front end by a beam and column suspension. At the rear end it rests on cast iron columns with expansion plates and rollers. This construction permits the boiler to expand and contract in any direction without interfering with the brick work. A superheater may be installed between the upper and lower banks of tubes.

Boilers with Curved Tubes.—Owing to the ease and precision with which tubes may be bent, designers have employed tubes of various shapes to secure certain advantages in boiler

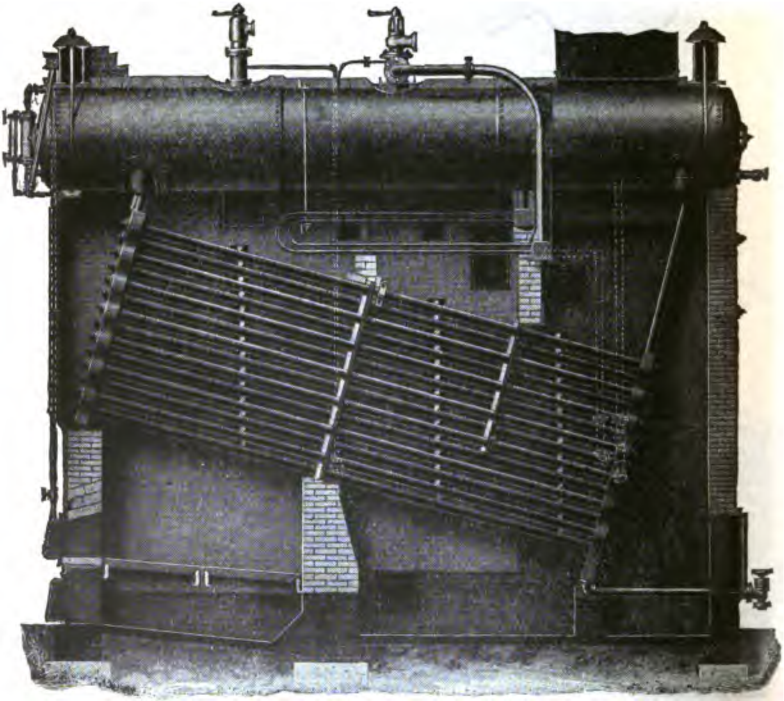


FIG. 3,692.—Babcock and Wilcox sectional *parallel* horizontal boiler with wrought steel inclined headers. The heating surface is composed of *tubes* expanded into headers of serpentine or sinuous form, which dispose the tubes in a staggered position when assembled. The headers may be either inclined as shown or vertical. The sections are attached at their rear lower end to a transverse mud drum which is tapped for blow off connection. The boiler is suspended by front and rear wrought steel supporting frames independent of the brick work to permit expansion and contraction without showing either the boiler or brick work. The feed water is introduced through the front drum head. From this point of introduction the water passes to the rear of the drum, downward through the rear circulating tubes to the sections, upward through the tubes of the sections to the front headers and through these headers and front circulating tubes again to the drum where such water as has not been formed into steam retraces its course. The steam formed in the passage through the tubes is liberated as the water reaches the front of the drum. The steam so formed is stored in the steam space above the water line, from which it is drawn through a so-called "dry pipe."

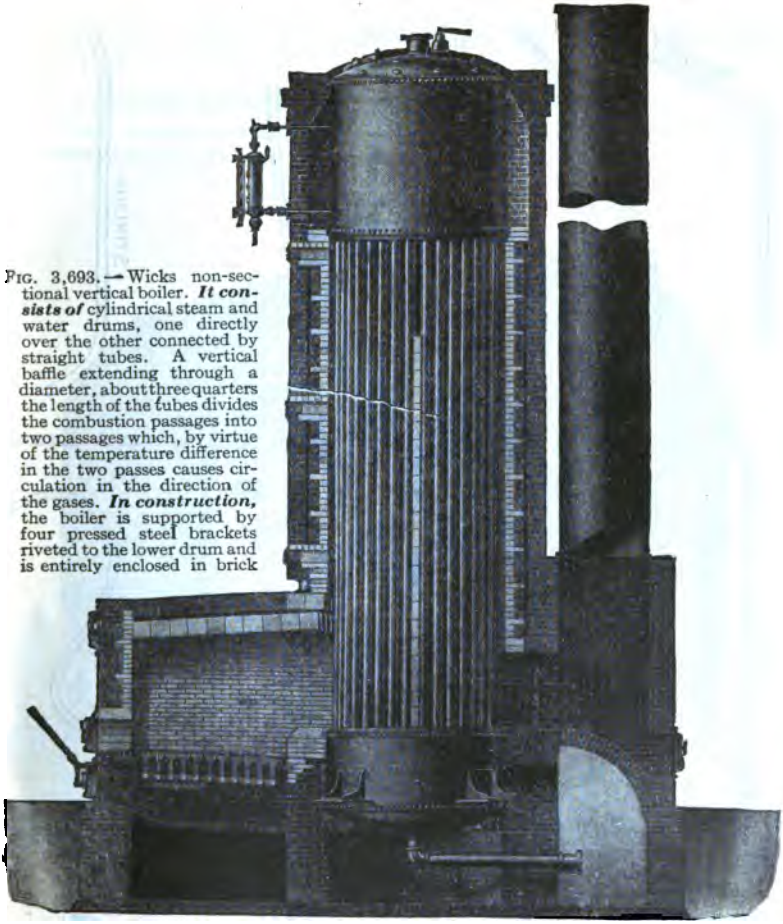
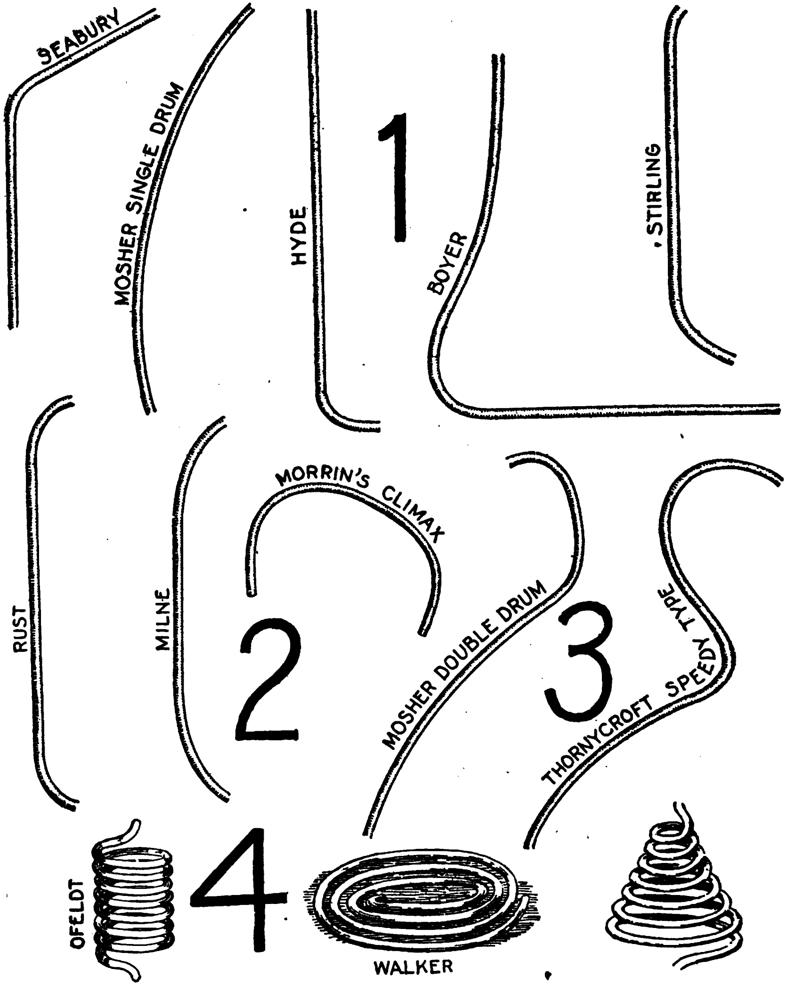


FIG. 3,693.—Wicks non-sectional vertical boiler. ***It consists of*** cylindrical steam and water drums, one directly over the other connected by straight tubes. A vertical baffle extending through a diameter, about three quarters the length of the tubes divides the combustion passages into two passages which, by virtue of the temperature difference in the two passes causes circulation in the direction of the gases. ***In construction,*** the boiler is supported by four pressed steel brackets riveted to the lower drum and is entirely enclosed in brick work. On a level with the water line and extending over the tubes in the first compartment of the upper drum is a baffle plate to deflect the water of circulation and prevent splashing or spraying water into the steam. Ordinarily, feed water is introduced into the steam drum below the water line and flows downward through the tubes of the second compartment. The feed water connection may, however, if desired, or conditions so warrant, be made in the bottom drum. The blow off is located in the center of the bottom of the lower drum, and the steam outlet in the center of the top of the steam drum with two safety valves on either side. In the convex head of the steam drum are placed one manhole and a number of hand holes, the lower drum being provided with a manhole.



FIGS. 3,694 to 3,706.—Various forms of curved or bent tube as used in curved tube boilers. They may be classed as: 1, single curve; 2, double curve; 3, triple curve, etc.; 4, circular form as helix, flat, and cone shaped spirals, etc.

construction. The results obtained by the use of bent tubes are, briefly,

1. Provision for expansion and contraction.

Thus, especially with boilers operated under forced draught, as on fast vessels there is less trouble with leaking joints.

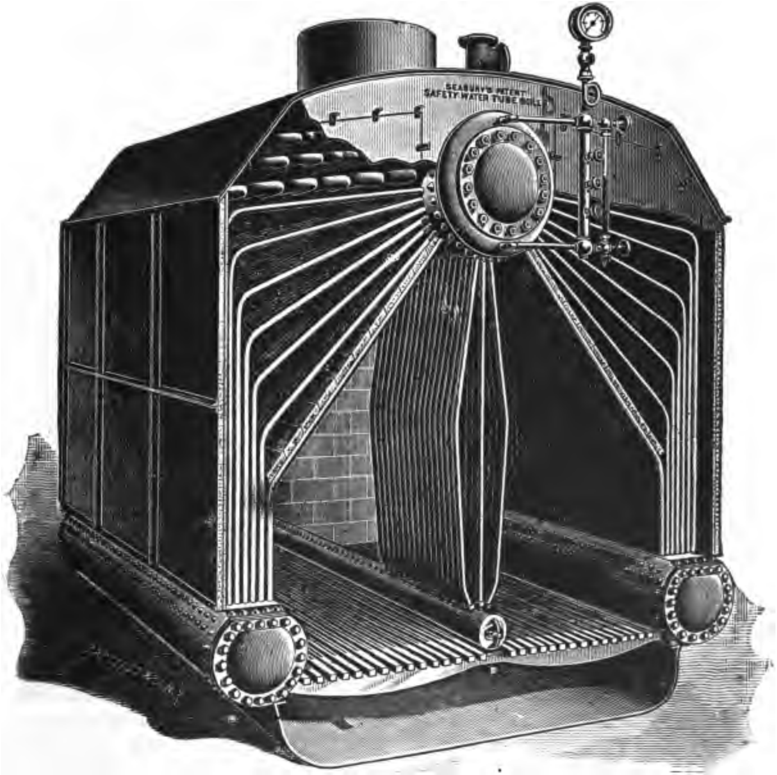


FIG. 3,707.—Seabury *single and double curve* bent tube boiler. ***In construction,*** there is a single steam drum connected to two lower or mud drums—one on each side—by two nests of bent tubes enclosing a large combustion chamber. The tubes are staggered so as to present the greatest amount of direct heating surface, and are so arranged as to facilitate their cleaning by means of a steam jet and hose. The feed water heater located on each side of the steam drum is made of pipe and extra heavy return bends. These boilers are built in sizes from 3 to 3,000 horse power.

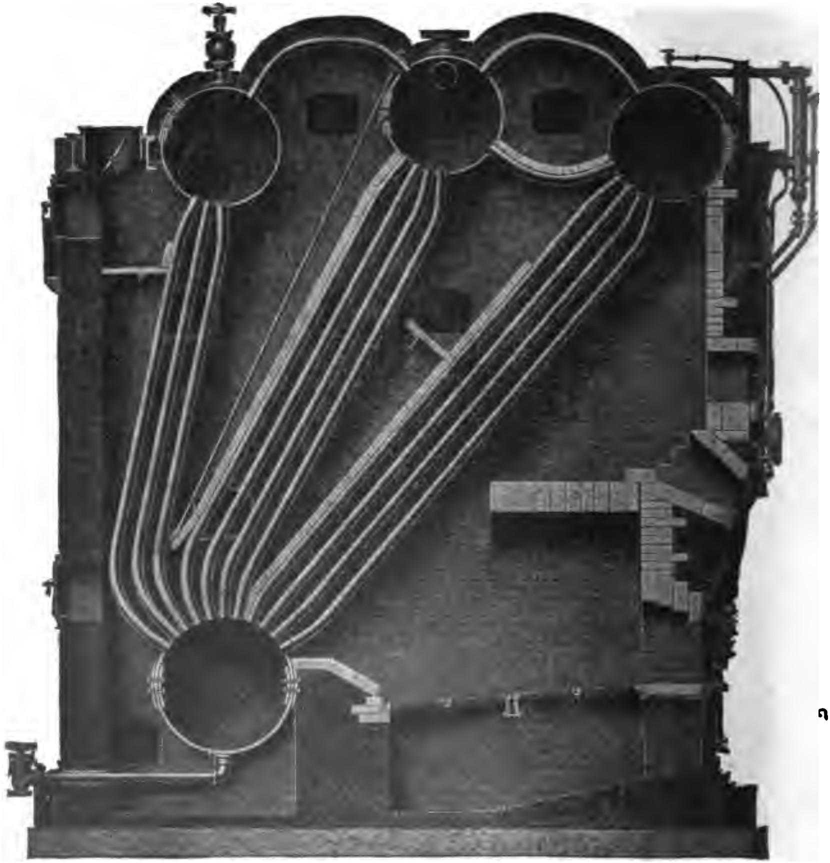


FIG. 3,708.—Stirling *double curve* bent tube boiler. It is built in a number of different designs, known as classes, to meet varying conditions of floor space and head room. All classes are of the same general design varying in depth, height and in the number and length of the tubes. The boiler consists of three transverse steam and water drums, set parallel, and connected to a mud drum by water tubes, so curved as to enter the tube sheets radially. The steam space of the center drum is interconnected to both the front and rear drums by a row of curved steam circulating tubes and to the water space of the front drum by water circulating tubes, the number of these latter tubes depending upon the class of the boiler. The main steam outlet is placed on the top of the center drum. Two independent safety valves are also placed on the top of this drum, and to one drum head a water column is connected. A feed pipe enters the top of the rear steam and water drum at the center and discharges into a removable trough, by

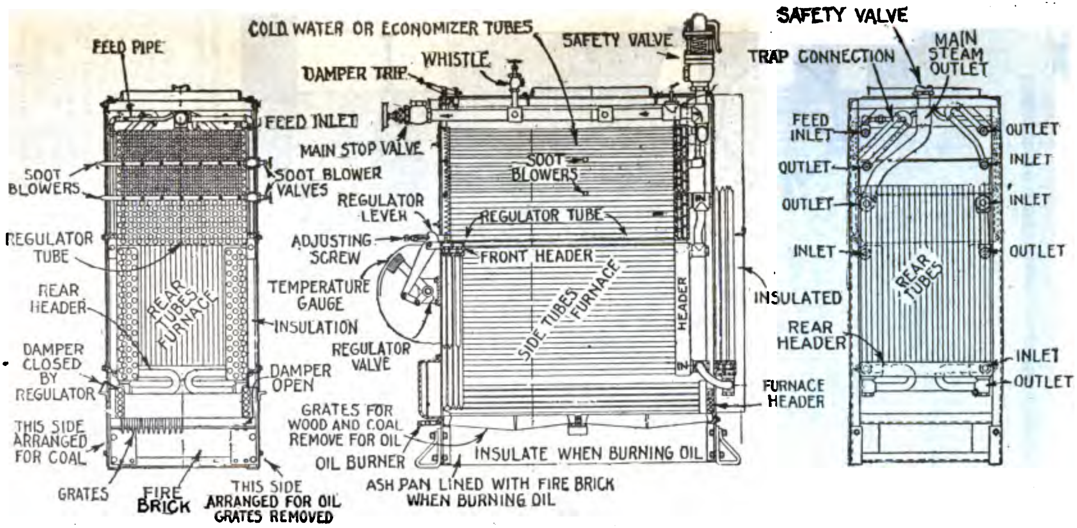


FIG. 3,709 (**A**, **B**, and **C**).—Talbot contra-flow water tube boiler. ***In operation,*** the circulation of water is maintained by a pump. delivering the feed water to the main check valve at the entrance to the furnace heater, from whence the water rises in a pipe to the regulator valve and passes around the door frame. The water then passes to the rear of the boiler to the uppermost set of tubes. In order to understand the circulation through the tubes, reference must be made to fig. 3,728 (page 2,098), which shows a typical header and tubes forming a single section, the path of water through it being indicated by arrows. Having passed through the first set of tubes and returned to the inner compartment of the header by way of the annular space in the generating tube, the water returns to the front of the boiler through a similar annular space in the next set of tubes and back to the outer compartment of the header by way of the inner field tubes. This process is repeated until the water has traversed to the opposite end of the header, where it passes out, through a trap connection, to the leader immediately below. Passing from header to header, the water has a general downward direction to the set of tubes which is on the left side of the furnace, looking toward the front as seen above at **C.** The circulation through all sections of tubes is the same. The expansion of one of the tubes of the last set in the furnace under the varying temperatures of steam contained within it is multiplied by means of levers, and is utilized as an automatic thermostatic control of both water and fuel supply. Arrangement is made so that the operator may easily and quickly adjust the thermostat to meet the demands. The thermostat controls the temperature of the steam.

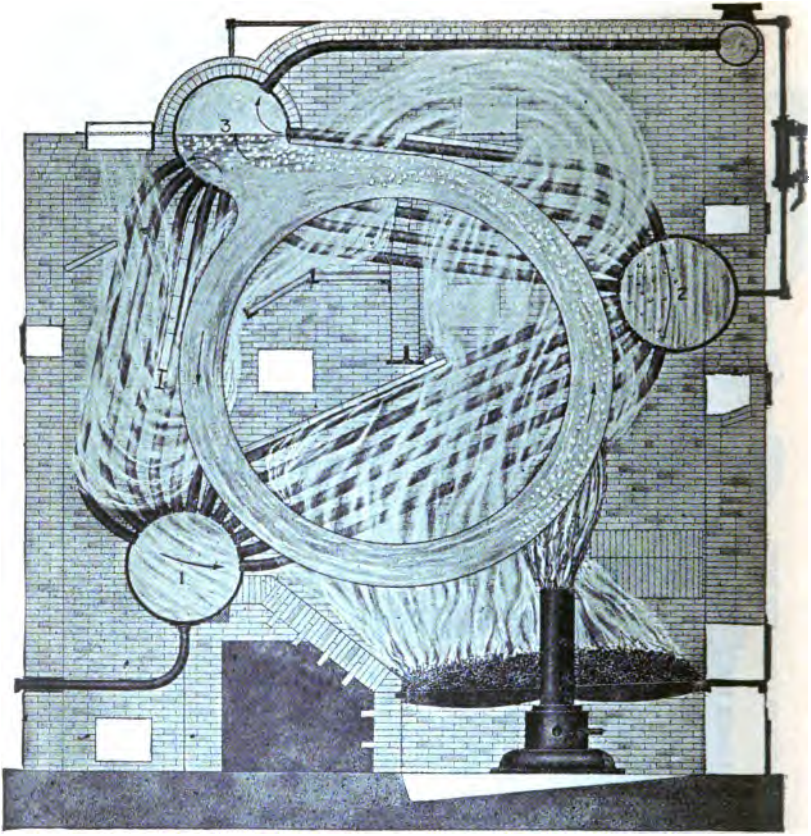


FIG. 3,710.—Badenhausen water tube boiler and superimposed glass ring with water inside and heated by a lamp illustrating the circulation. The boiler *consists of* two water drums, one steam and water drum, and a steam header, all connected by means of tubes. The water is fed into drum 3, flows down the rear bank of tubes to drum 1, thence upwardly over the fire to drum 2, and then back to drum 3. The steam is disengaged from the water as it enters drum 3, and, after passing through the roof tubes where it is superheated from 5 to 10° F., enters the steam header. From there it passes through the steam outlet to the steam line. The boiler is supported by means of steel framing independent of the brickwork. Drum 3 rests on beams. Drum 2 is suspended from heavy turned bolts arranged to accommodate any expansion. Drum 1 is suspended from tubes only. The steam header is supported at both ends on steel angles carried up from the main boiler frame. Thus it will be seen that each unit of the boiler is free to expand. Asbestos is placed around the drum ends where they enter the brickwork thus making an expansion joint to allow for free movement of the drums where the expansion of the unit may dictate.

2. Longer tube length.

Thus reducing the number of expanded joints.

3. Flexible disposition of the heating surface.

Thus, in special cases, suitably locating the heating surface without mechanical difficulties, as to give good circulation.

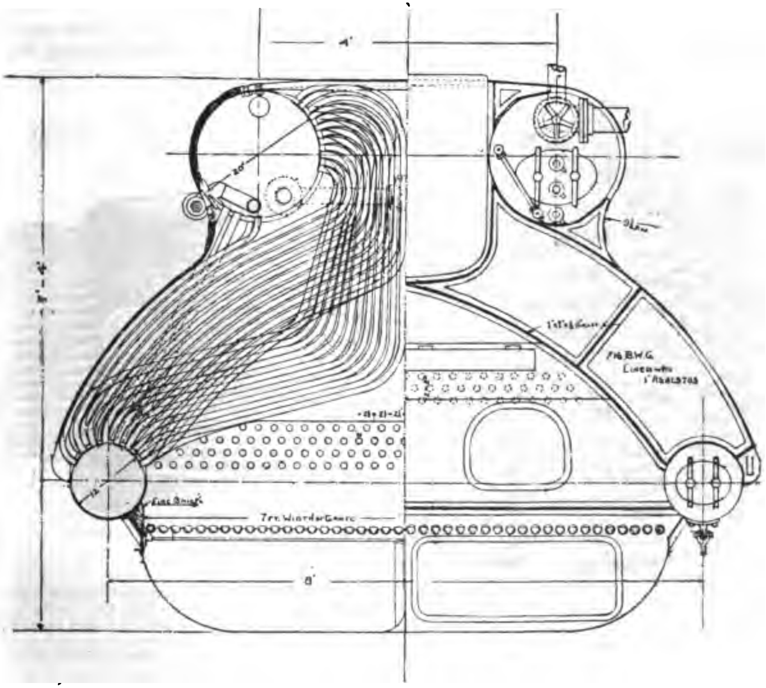
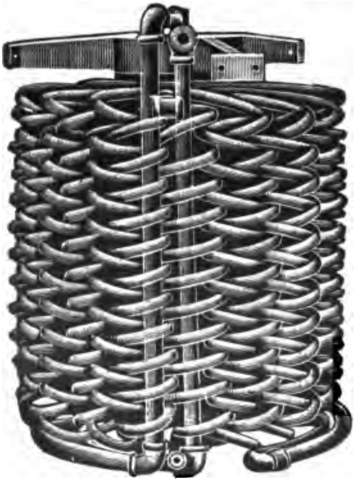


FIG. 3,711.—Mosher *triple curve* bent tube double drum, over discharge marine boiler. ***In construction,*** there are two steam drums and two mud drums which are connected by rows of bent tubing, inclined and connected, above and below, as shown. The two upper drums are also connected, below the water line, by a length of tubing, thus completing the water circulation. An early design of this boiler was for the fast steam launch ***Norwood*** (speed 30 miles per hour, and famous in its day), shown in fig. 3,122, page 1,620. The proportions of this boiler were: Heating surface 1,000 square feet; grate area 26 square feet; center of gravity very low; tubes 1-inch diameter solid drawn; weight of boiler 2½ tons; length 7 feet 3 inches; breadth 6 feet; height 3 feet 6 inches. The boiler supplied steam to a triple expansion engine, size 9, 14½, and 22, by 9 in. stroke, about 800 *r.p.m.*

4. In large boilers, one manhole to be removed instead of individual tube hand hole plates for cleaning.

This does not apply to all straight tube boilers, there being a number of makes, as the Vogt, for instance, in which access to the tubes is through large drums, instead of tube plates.

While, of course it takes longer to remove a multiplicity of hand hole plates than a manhole, it should be noted that in the former arrangement the tubes are more accessible for cleaning, and a straight tube is more easily cleaned than a curved tube, in fact some designs of curved tube are so complex as to practically preclude cleaning. In small boilers cleaning such tubes is impossible.



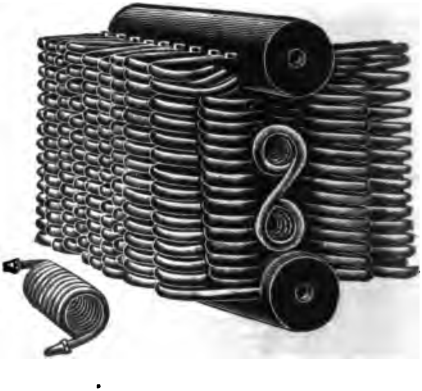


Fig. 3,712.—Ofeldt circular form or *helix curve* bent tube vertical drum automobile type boiler. This is a true coil, as distinguished from the so called coil boiler in which the "coils" are made up of straight pipes connected in series by return bends. The Ofeldt boiler ***consists of*** a central vertical drum, surrounded by a number of pipe coils which are connected to the drum at its extremities. The drum holds a reserve of water, which, when the boiler is in operation, circulates through the coils absorbing heat from the fire, and re-entering the drum at the top as water and steam. The amount of water in the drum varies from three gallons in the smallest size to eight gallons in the 24-inch boiler. Steam is taken from the top of the drum and passed through a superheater before delivery to engine.

Figs. 3,713 and 3,714.—Ofeldt circular form or *helix curve* bent tube horizontal drum marine type boiler and detail of coil. The boiler ***consists of,*** two horizontal drums connected on each side by numerous vertical *up flow* coils. Between the two series of coils are a set of *down flow* coils connected to the two drums. The cooler water in the upper drum flows down through these coils to the lower drum, thence up through the up flow coils absorbing heat from the fire and re-entering the upper drum as steam and water.

5. Ease of making repairs depends on the design.

In some boilers, as for instance, the Mosher, any tube may be removed without disturbing the others, whereas, in some other types it is necessary to start at the beginning of the row and remove all tubes up to the one damaged.

6. Curved tubes designed for over-discharge give a large space above the grate, thus improving the combustion efficiency.

The arrangement is made with only a small increase in the height of center of gravity, an important point in certain types of vessel.

Ques. Mention one objection to bent tubes.

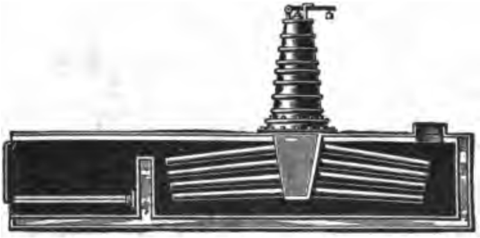


FIG. 3,715.—The first porcupine boiler. Built in 1804 by Col. John Stevens and operated upon the Hudson river in a little steam boat 68 feet long by 14 feet beam. The boiler was of the *single parallel tube* double bank type and contained 100 tubes 2 inches diameter by 18 inches long. One end of each tube was fastened to a central water leg, the other end being closed as shown. The vessel attained a speed of seven miles per hour and was one of the earliest examples of the use of water tube boilers for marine purposes.

Ans. In the case of repairs, especially in remote regions, they are not so easily obtained as straight tubes, entailing more or less vexatious delay with accompanying loss due to shut down of plant.

Closed Tube or Porcupine Boilers.—This type of boiler consists essentially of *a tube sheet into which are expanded or screwed a number of tubes having their exterior ends closed*, and which form the water tubular heating surface.

Porcupine boilers may be classed as

1. Parallel tube,
2. Radial tube,

according as the tube sheet is, 1, a flat plate, or 2, a cylindrical drum, and as

1. Single tube,
2. Double tube,

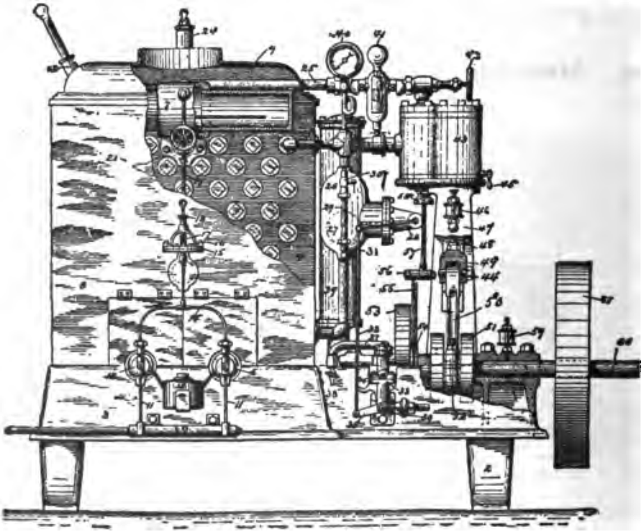


FIG. 3,716.—Shipman single *parallel tube* porcupine boiler; a widely known and extensively used boiler in its day. It was employed on self-contained petroleum burning outfits for small powers. The boiler ***consists of*** tubes about 18 inches long which are screwed into a flat oblong chamber at one end and closed at the other. The illustration clearly shows the details of construction. The large tube seen at the top serves as a steam drum.

according to the *absence* or *presence* of inner or Field tubes which serve to promote circulation.

Figs. 3,716 and 3,717 show respectively the parallel and radial types, these being single tube boilers, and figs. 3,718 and 3,719 a double tube boiler of the parallel tube class.

Boilers with Tubes in Series Parallel.—By a stretch of the imagination the term *series parallel* may be applied to the tube arrangement found in some of the multi-drum boilers of very large capacity, with drums in common forming a series connection between two parallel sections or separate drums connected by equalizer tubes examples of the two types being shown in

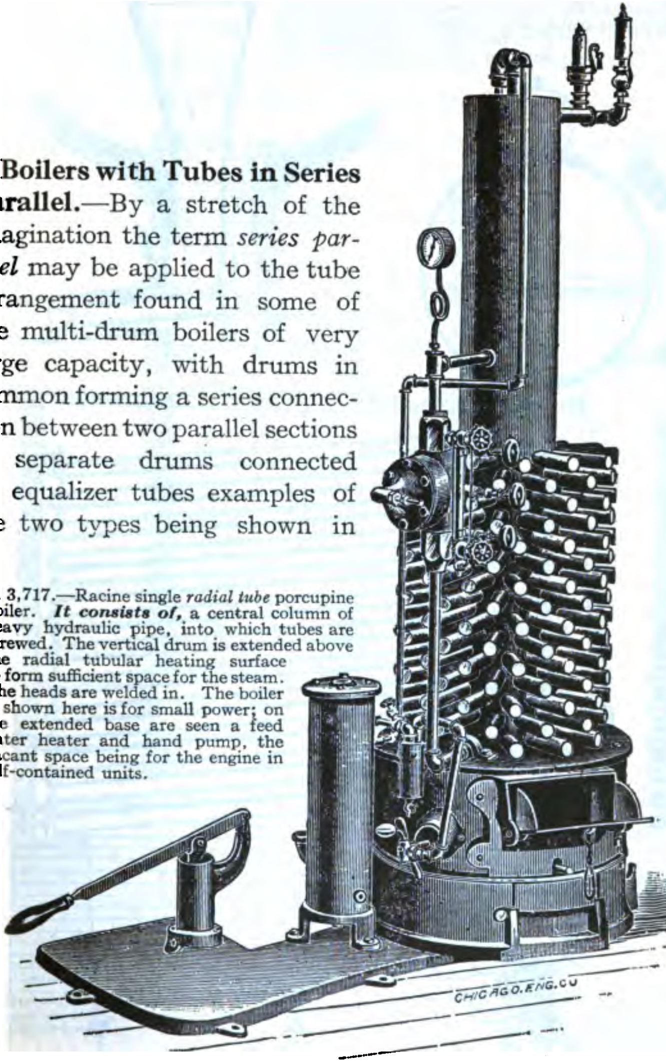
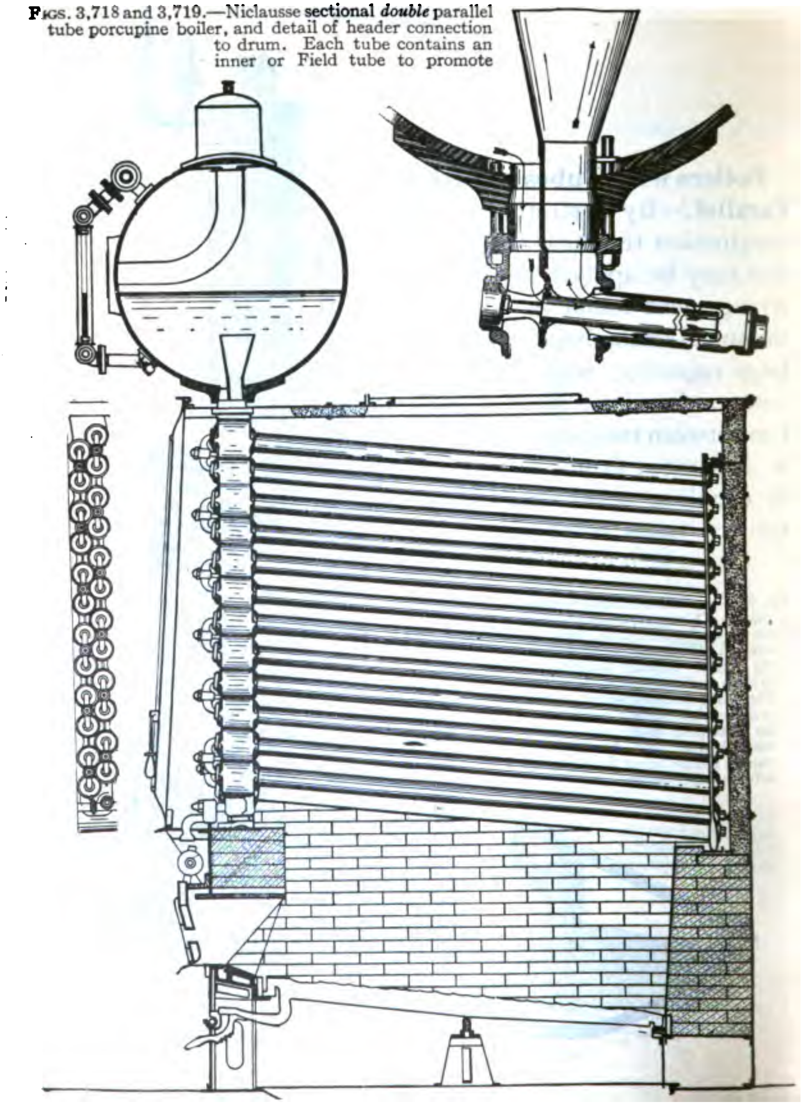


FIG. 3,717.—Racine single *radial tube* porcupine boiler. ***It consists of,*** a central column of heavy hydraulic pipe, into which tubes are screwed. The vertical drum is extended above the radial tubular heating surface to form sufficient space for the steam. The heads are welded in. The boiler as shown here is for small power; on the extended base are seen a feed water heater and hand pump, the vacant space being for the engine in self-contained units.

FIGS. 3,718 and 3,719.—Niclausse **sectional** ***double*** parallel tube porcupine boiler, and detail of header connection to drum. Each tube contains an inner or Field tube to promote



figures 3,720 and 3,721 respectively. The arrangement here shown lends itself to very large powers, the unit virtually comprising several boilers combined into one.

Up Flow and Down Flow Boilers.—According to the way

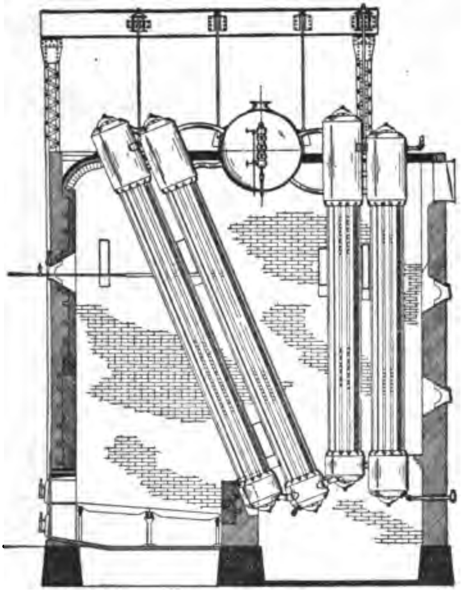


FIG. 3,720.—Bigelow-Hornsby multi-drum boiler with tubes in *series parallel* by *equalizer tube* connectors. ***The general circulation*** of this boiler is down the rear sections and up the front, and in addition to this there is a rapid circulation in the individual units. The feed enters the top rear unit drums and mingles with the downward circulating currents in the rear tubes and then passes up the tubes in the front units. It will be noted that the rear vertical units (comprising almost half of the heating surface), which are in contact with the cooler gases of combustion, must be traversed by the feed water before it can come in contact with the direct heating surface over the furnace.

FIG. 3,718 and 3,719.—*Text Continued.*

circulation. This is accomplished as shown in fig. 3,719. Here, as indicated by the arrows the water from the down flow section of the header traverses the inner tube and returns by the outer tube to the up flow section thus a thin circular film of water is presented to the heating surface rendering it very effective and at the same time producing rapid circulation, but at the expense of extra weight and complication.

in which the water passages are arranged, the circulation may be directed upward or downward. Although most boilers work on the upflow principle, Rankine states in favor of downflow circulation as follows:

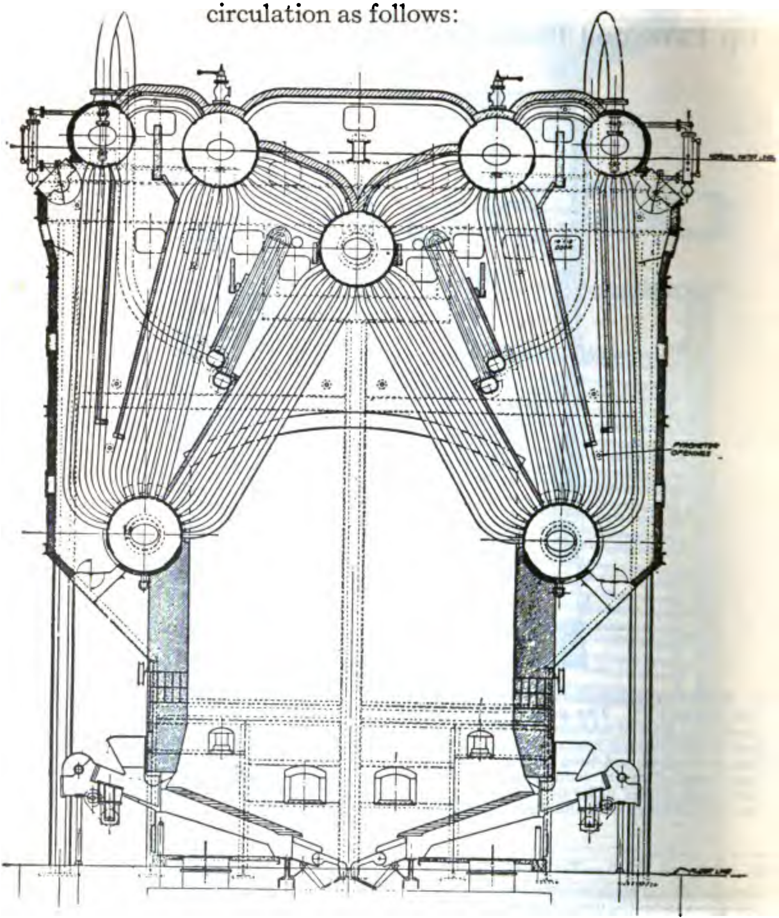
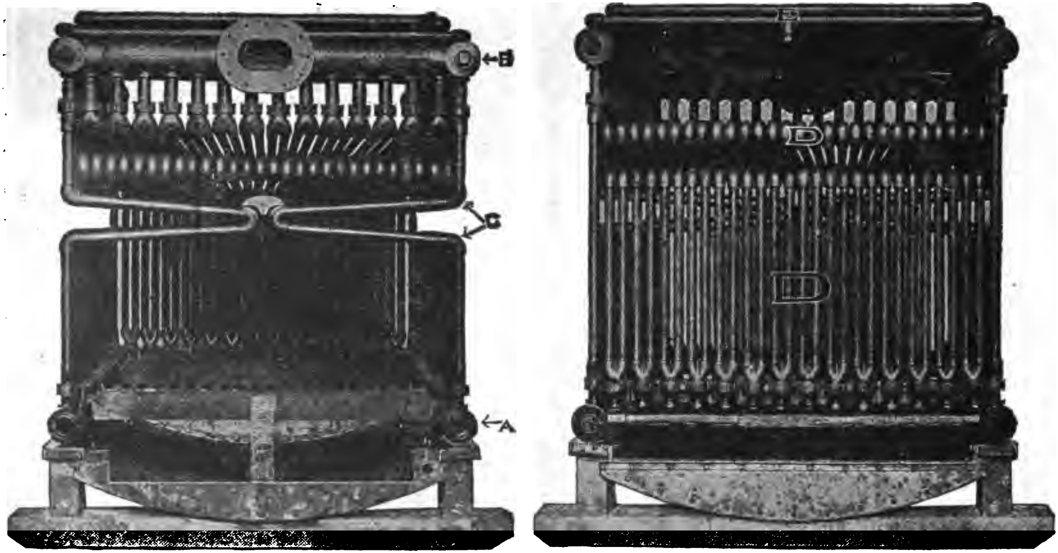


FIG. 3,721.—Connelly multi-drum boiler of very large horse power with tubes in ***series parallel*** by ***drum in common*** connection; fitted with mechanical stoker and built for sizes ranging from 1,000 to 4,000 horse power.



FIGS. 3,722 and 3,723.—**Almy sectional combined series parallel pipe boiler with external transverse drum. In the type shown** ¾-inch standard pipe is used. The side and forward aft sections of the heating surface are made up of two series connected elements joined in parallel by special fittings. The *side sections* C, rise from the bottom manifold A, to a proper height to form the crown of fire box; they then extend halfway across the furnace and back again, then rise vertically to the top manifold B. The *fore and aft sections* D, rise from the bottom manifold A, at the back of the furnace to a proper height and pass three times over the side sections and connect into top manifold B, at the front. The *heater* E, is a flat continuous series connected section.

"In a steam boiler it is favorable to economy of fuel that the motion of the water and steam should, on the whole, be opposite to that of the flame and hot gas of the furnace, in order that the hottest particles of each may be in communication with the hotest particles of the other, and that the minimum difference of temperature between the adjacent particles of the two may be the gratest possible. Thus, if there be a feed water heater

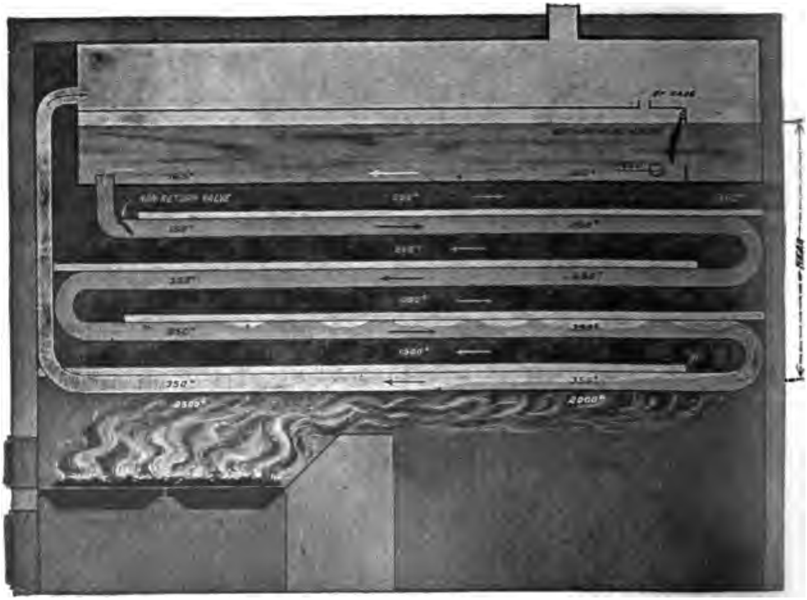
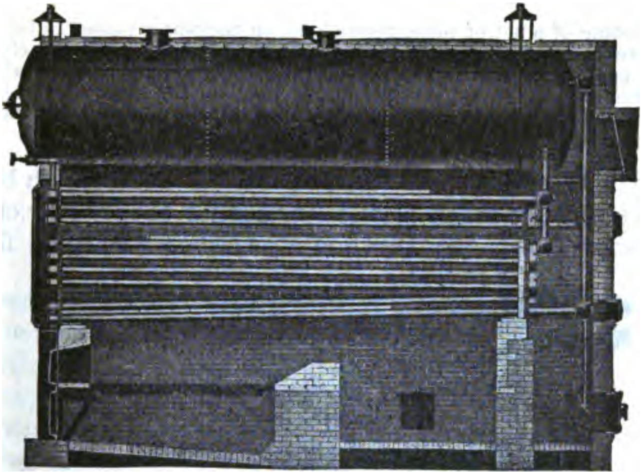
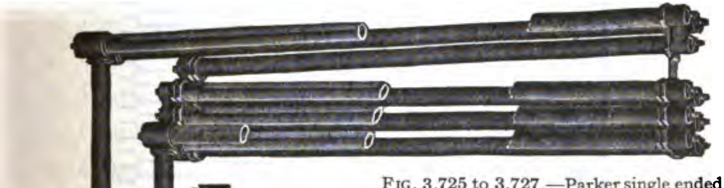


FIG. 3,724.—Diagram of Parker sectional *down flow* boiler. The drum has separate chambers for water and for steam, with a valve between to prevent priming. The tubes are arranged to form continuous passages, termed elements, leading downward from the water chamber, with direct upcasts from the bottom ends to the steam chamber. A non-return valve at the top of each element prevents reversal of the flow. The water fed into the drum seeks its level in the upcast. When heat is applied the water in the upcast is soon discharged into the drum by the expansion of the steam formed in the lower tube. The water then runs down from the drum with an effort to retain its level in the upcast, which is frustrated by continuous evaporation, and the result is a strong and rapid flow, impelled by the gravity head of water. The flow of water and steam is opposite to the gases, and as the heat transfers from the latter to the former it is carried back toward the point where it was originally generated. This is an application of the regenerative principle, which has been profitably used in many of the arts, and its application to boiler practice affords a material gain in economy. When a drop in pressure occurs, the anti-priming valve closes, and the difference in pressure created between the two chambers keeps the valve closed while the drop continues; this effectually prevents priming. ***In operation***, the coolest water passes through the upper or economizer elements where it comes in contact with the coolest gases. Steam is delivered direct from the hottest part of the furnace into the steam chamber.





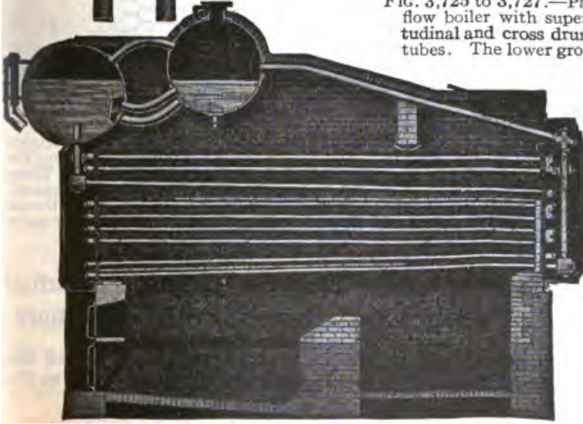


FIG. 3,725 to 3,727.—Parker single ended down flow boiler with superheater showing longitudinal and cross drum types and detail of tubes. The lower group of tubes in the down flow generating section and the upper group feed the water heater. The superheater consists of U tubes joined to two headers and located in the combustion chambers below the generating tubes.

consisting of a set of tubes through which the water passes to be heated before entering the boiler, that apparatus should be placed near the chimney. The coolest portions of the water in the boiler should if practicable and convenient, be contiguous to the coolest part of the furnace; and if there be apparatus for superheating the steam, that apparatus will be most efficient if placed in the hottest part of the furnace."

The downflow principle has been utilized in some flash boilers and a few water tube boilers. An example of the latter class is the Parker boiler, the operation of which is shown in figures 3,724 to 3,727. Here the water as it descends with gradual rise of temperature travels toward the hotter part of the furnace.

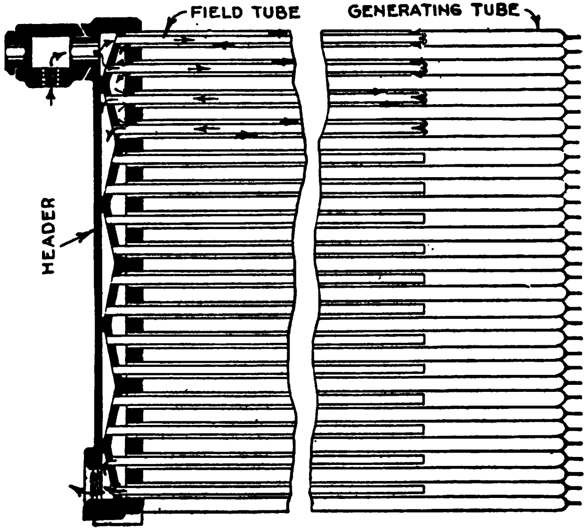


FIG. 3,728.—Talbot boiler header and tubes. The header consists of two sets of overlapping compartments, into one of which is screwed the open end Field tubes and into the other the generating tubes. The end of each generating tube is welded together so as to close it. These closed ends are free to expand and are supported in front by perforated sheets of metal. Both tubes are secured by screwed joints with threads having double the standard pipe thread taper which makes it easy to remove them, the fit is sufficiently tight for 1,000 lbs. pressure using standard weight pipe.

A question which naturally presents itself is whether the life of the lower tubes be shortened because of the more severe conditions due to the down flow principle.

CHAPTER 66

SPECIAL BOILERS

There are a few types of boilers, not described in the preceding chapters, that are of unusual character, and here designated as *special*.

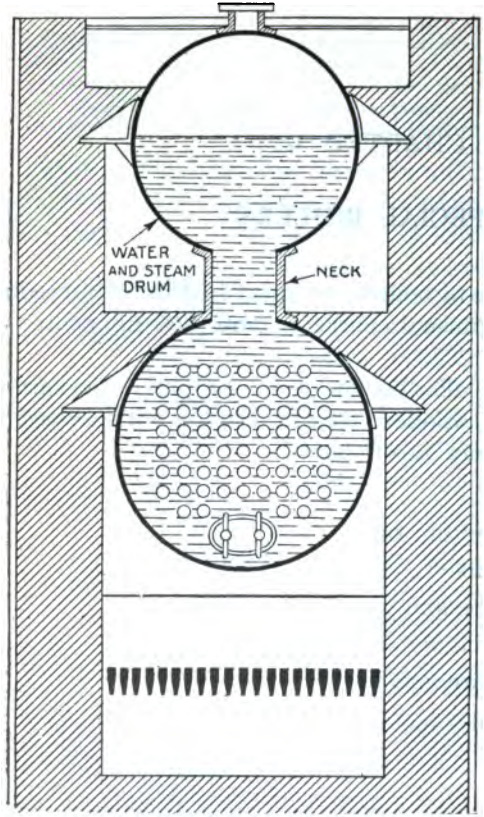
Examples of these peculiar boilers are to be found in the various divisions previously mentioned, that is, classed with respect to heating surface that may be of the

1. Fire tube.
2. Combined flue and fire tube.
3. Water tube (or pipe).
4. Combined fire tube and water tube.
5. Combined shell and water tube.
6. Combined shell, fire and water tubes.

or other special types not included in the above list.

1. FIRE TUBE BOILERS

Duplex and Triplex Fire Tube Boilers.—An inherent defect in the horizontal return tubular boiler is its limited diameter, due to the fact that part of the shell being exposed to the intense



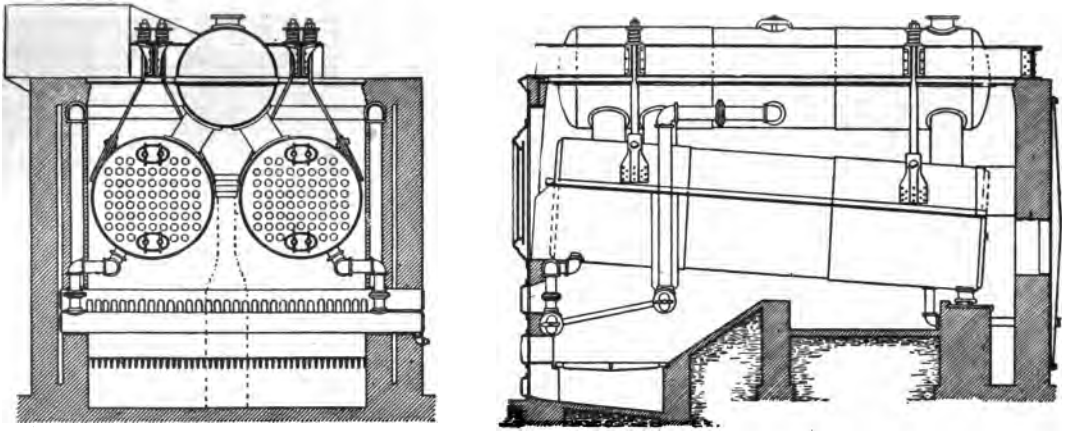
heat of the furnace, the shell cannot exceed a certain thickness, otherwise the outer portion of the metal especially at the riveted joint would become overheated. This, and the constantly increasing size of unit demanded have resulted in various modifications, some more or less freakish in their character.

Fig. 3,729 shows the duplex arrangement, being an attempt to increase the heating surface of a shell boiler of given diameter by utilizing all the tube sheet for tubes, and connecting the shell (by short necks) to a steam and water drum as shown.

Fig. 3,729.—Duplex horizontal return fire tube boiler consisting of a lower tubulous shell connected by necks to an upper drum.

Although the connecting necks are made as large as possible, the circulation is poor. The hot gases pass from the furnace underneath and around the lower shell, thence through the tubes, and back under the drum.

According to Barr, boilers thus constructed have not sufficient advantages over the ordinary single shell type to pay for their extra cost.



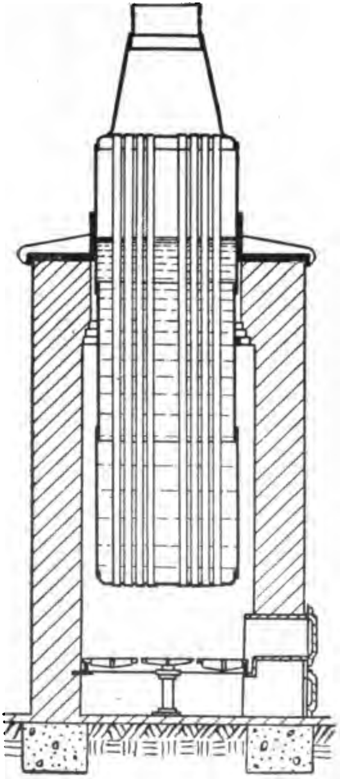
FIGS. 3,730 and 3,731.—Triplex horizontal return fire tube boiler consisting of two tubulous shells placed side by side and connected by necks to a corner upper drum. The boiler is provided with a Hawley down draught furnace.

Figs. 3,730 and 3,731 show a further development consisting of two tubular shells connected to a drum by necks and called *thimble* tubes for want of a better name.

In operation water circulates upward through the connections and downward through the rear connections, being so arranged as to induce and maintain a longitudinal circulation in a circuit through the upper drum and lower shells. The combination setting partly supports the tubes from above by spring slings and partly from below by rollers, one end being fixed and the other free to allow for expansion.

Horizontal Fire Tube Boiler Vertically Set.—Another method of increasing the capacity of a shell of given size is the vertical setting shown in figure 3,732. In this arrangement a greatly increased number of tubes may be used as the entire tube sheet may be filled with them, thus considerably increasing the heating surface.

Although the return flow of the hot gases is not obtained in the vertical setting. the same economic effect is obtained by decreasing the diameter of the tubes, thus lowering the stack temperature to the same degree as is obtained with the horizontal return flow setting; in fact, tests indicate that the performance of the vertically set boiler is the same as the horizontal return flow setting.



The boiler, as shown, is supported by an iron collar riveted to the shell and of proper dimension to support the boiler in place without bringing undue strain upon the rivets which fasten the collar to the shell.

Where floor space is limited and there is sufficient height, the vertical setting is desirable, provided the feed water be such as will not foul the lower sheet.

FIG. 3732.—Vertical setting for modified horizontal tubular boiler. Since the object of this arrangement is to secure maximum capacity for a given size shell as well as to economize floor space, the entire tube sheet area should be utilized for tubes using a large number of small diameter tubes rather than large tubes, in order that the stack temperature will be such as gives satisfactory efficiency. The setting should be continued up to within a few inches of the water level to obtain as much shell heating surface as possible.

Vertical Extended Internal Fire Box Fire Tube Boilers.—This is a natural development of the vertically set tubular boiler just described, in that it eliminates the brick setting, thus

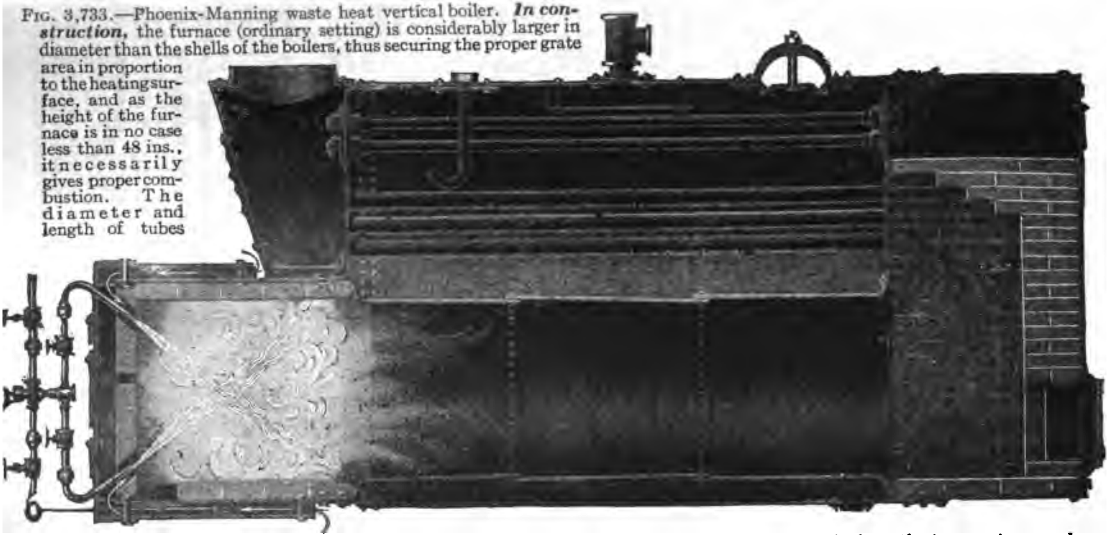
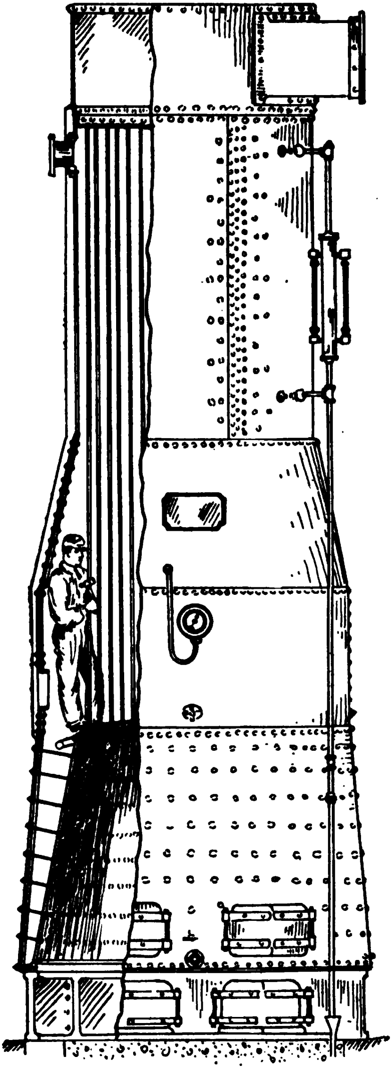


FIG. 3,733.—Phoenix-Manning waste heat vertical boiler. ***In construction,*** the furnace (ordinary setting) is considerably larger in diameter than the shells of the boilers, thus securing the proper grate area in proportion to the heating surface, and as the height of the furnace is in no case less than 48 ins., it necessarily gives proper combustion. The diameter and length of tubes are so proportioned that the heat is so thoroughly absorbed by the time it reaches the smoke box, the temperature rarely exceeds the temperature due to pressure of steam more than 40 to 50 degrees, which amount is necessary to give the proper chimney temperature. The water line is carried up to about 75 per cent. of the height of the tubes, thus allowing space for steam, which is superheated by the heat that passes through the upper end of the tubes, giving ordinarily not less than 2 per cent. superheat, which insures perfectly dry steam. The barrel or shell is made in two courses of one sheet each, the longitudinal seam being made butt and strap joint and treble riveted. These boilers are made of open hearth steel, with a tensile strength of 55,000 to 62,000 pounds. A cleaning chain is provided for the bottom of the water leg, which runs around the entire furnace, and is so arranged that the dirt and sediment may be easily loosened and removed. The boiler is fed through a perforated internal brass pipe, as shown in cut, thus securing uniform distribution of water, and avoiding the danger of damage to tubes and shell by any sudden expansion or contraction. The firing door is made with flanged opening, so that there is free water circulation all around the opening. The fire box sheet is made taper on all sizes, making the diameter slightly less at the top, which increases the water space, and which also reduces the unstayed area of the crown sheet or fire box head. Hand holes can be put in on a level with the crown sheet, and a sufficient number of them to permit of a scraper being used between every row of tubes for the purpose of cleaning. The tubes in all sizes are set in four sections, giving two central cross spaces at right angles to each other for the purpose of more thoroughly cleaning the crown sheet, as well as increasing the circulation.



economizing flow space in a still higher degree.

The design also provides adequate grate area for the very great amount of heating surface crowded into a shell of small diameter. These features are embodied in the Phoenix-Manning boiler, figure 3,733, and with improved construction in the Smith-Manning boiler, figure 3,734.

Manning boiler.—As shown in fig. 3,734, it is very high in proportion to its diameter in order, 1, to obtain large capacity on small floor space, and 2, to reduce the stack temperature to that giving high efficiency.

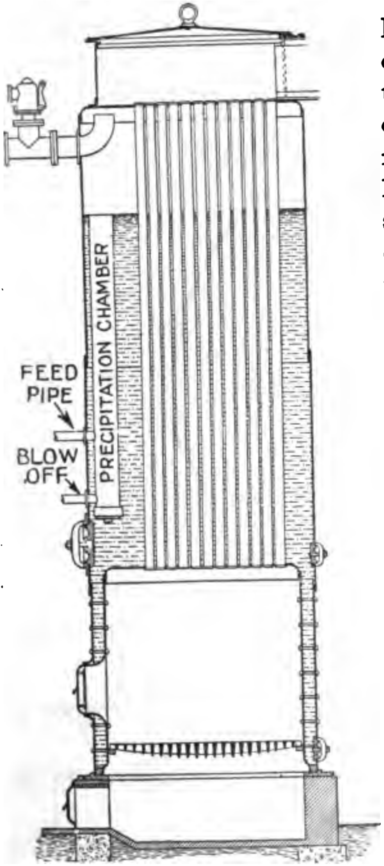
In order to obtain adequate grate area for the large amount of heating surface the shell diameter is enlarged at the furnace by a doubled flanged ring as shown, thus the diameter of the furnace is made equal to or larger than that of the shell instead of being reduced as in the case of the ordinary vertical boiler.

The tubes are arranged in concentric circles with a space at the center for circulation. The double flanged ring also provides for expansion which, because of the extra length of the boiler, is an important feature.

Smith boiler.—This is a modification of the Manning boiler. In place of the double flanged ring of the latter, there is a conical enlargement of the shell above and around the furnace, and a corresponding enlargement of the furnace walls as shown in fig. 3,734. The objects of this arrangement

Fig. 3,734.—Smith - Manning vertical tubular boiler. The fire box is conical permitting a free circulation of water and the tube sheet is curved for strength.

are 1, to avoid the ring construction which was an element of weakness, 2, to provide a space around the tubes large enough for a man to walk in to examine and clean the crown sheet and other interior surfaces, and 3, to provide additional water space and thus render the boiler less sensitive to changes in operation.



Vertical Radial Fire Tube Boilers.—A defect of the vertical fire tube boiler is position of the lower tube sheet directly over the fire where scale or sediment is baked by the intense heat, and, as usually constructed, the impossibility of cleaning the tube sheet rendering this type of boiler undesirable for feed water containing impurities. To overcome this trouble Reynolds conceived the idea of spacing the tubes in radial lines, and providing a large hand hole at the tube sheet level where these lines converge thus rendering the spaces between the radial rows of tubes accessible for cleaning.

The features of the design are shown in figs. 3,735 and 3,736. In fig. 3,735, the space at the left side left vacant by the tube arrangement is utilized by an internal stand pipe or reservoir through which the feed water passes from the bottom and overflows at the top.

In traversing this reservoir, a considerable portion of the impurities is

FIG. 3,735.—Reynolds boiler showing method of introducing the feed water. By raising the water level in the boiler slightly above the top of the feed column, the latter may be utilized as a surface blow off to eject scum or light impurities collected on the surface of the water.

precipitated and caught in the bottom of the reservoir, where it may be blown off through the lower connection.

Vertical Return Fire Tube Boilers.—An attempt to improve the efficiency of the vertical boiler without increasing its length and reducing the size of the tubes, resulted in the return or two pass arrangement shown in figure 3,737. Here the hot gases after passing through the tubes directly above the furnace return downward through the outer circle of tubes, thence to stack.

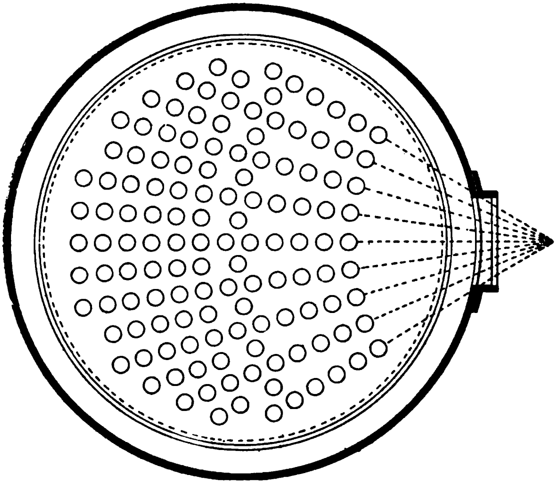


FIG. 3 736.—Detail of crown sheet of Reynolds boiler. The radial tube spacing facilitates cleaning the crown sheet.

In order to avoid the use of stay bolts and permit placing the outer ring of tubes, a corrugated furnace is used.

To further increase the efficiency the combustion space is of great height obtained by placing the grate in an extension of brickwork of conical shape directly below the boiler. The wall

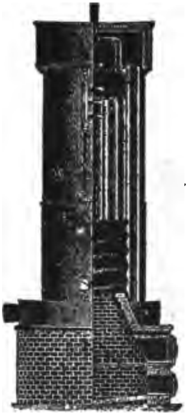


Fig. 3,737. — Webber vertical return fire tube boiler with extended brickwork furnace and corrugated combustion chamber.

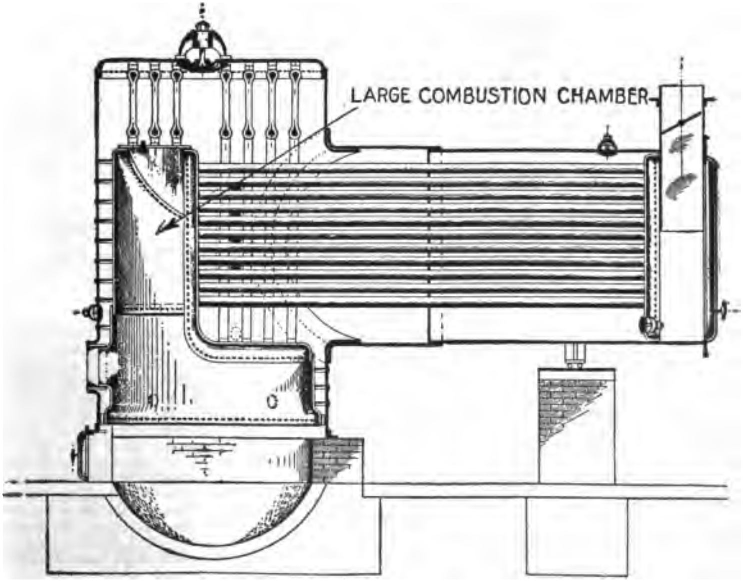


Fig. 3,738.—Fitzgibbons combined vertical-horizontal boiler with horizontal fire tubes. As can be seen the design permits a very roomy combustion chamber which increases the furnace efficiency besides adding very effective heating surface.

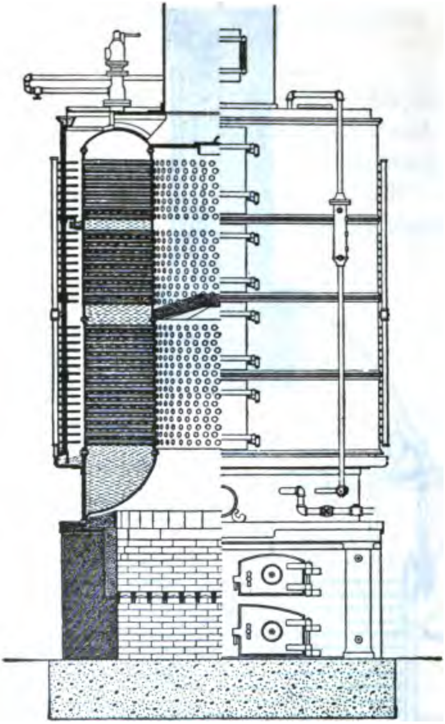
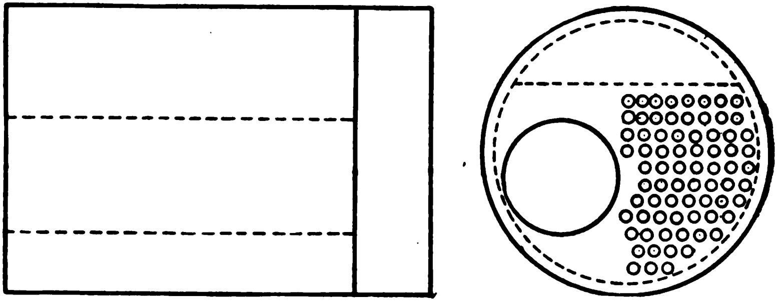


FIG. 3,739.—Berry vertical boiler with horizontal return fire tubes. ***It consists of*** two vertical cylindrical shells, united at the top by a crowned ring and at the bottom by a conical crown sheet. These rings do not require bracing, and accommodate any difference in expansion that may occur. Tubes radiate from the inner to the outer shell, uniting and bracing them and forming a structure of great strength. A deflecting arch of fire brick is placed in the internal flue at a point above about two-thirds of the submerged tubes, and a casing or smoke flue surrounds the boiler on the outside. The boiler is supported on the side walls of the furnace, which is square and lined throughout with an independent fire brick lining. The gases rise into the internal combustion chamber, are deflected by the arch, and pass through the tubes to the outside flue, thence upward and inward through the middle section of tubes to the internal flue, thence upward and outward through the superheating tubes, thence upward and inward over the top of the boiler to the stack. The circulation is up the inside and down the outside. One-half the area is maintained for circulation on the inside flue-sheet and three-quarters on the outside sheet. A manhole is provided for entering at lower shell, which space is unobstructed, and two blow off cocks are provided at base of boiler. The casing is lined with an insulating material and is mounted on wheels which run upon a track secured to the boiler. The joints are made by a gravel pocket, so that the casing may be easily revolved. Doors are provided from top to bottom, which, by revolving the casing, may be brought opposite any part of the boiler for inspection, cleaning or repairs.

being perforated as shown by radial holes through which air may be admitted above the fire to improve combustion.

Modified Clyde Type Boilers.—An objection to the Clyde and Scotch boilers is the poor circulation because, as usually



FIGS. 3,740 and 3,741.—Single flue Clyde type boiler with furnace on side. *In this arrangement* there being more heating surface on one side than the other, circulation is promoted and the dead water which collects under the flue on the ordinary type is avoided. Since the efficiency of the flue heating surface, being on the front pass, is greater than that of the tubes, a large number of tubes should be used otherwise the result sought may not be obtained.

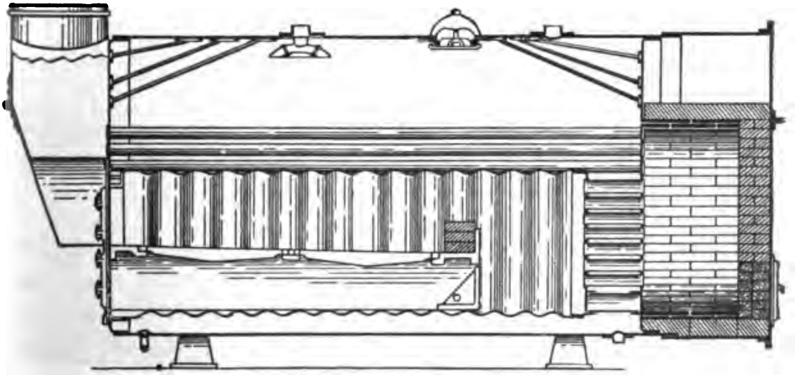


FIG. 3,742.—Murray modified Clyde type boiler with short fire tubes at rear of furnace flue, the object being to promote circulation under the flue.

constructed, the water lies dead in the bottom of the boiler, the heat from the furnace not reaching to any degree the bottom of the boiler. To remedy this defect numerous devices have been applied.

Fig. 3,742 shows one arrangement in which the furnace instead of extending the length of the boiler is connected to a number of short tubes. The effect is to produce rapid upward circulation in that end of the boiler and draw in that direction the water under the flue.

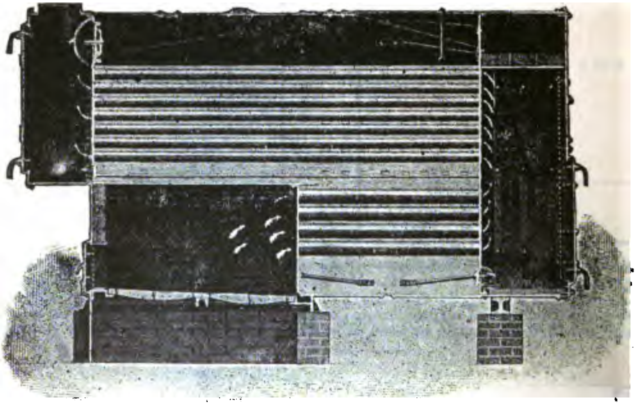


FIG. 3,743.—Casey-Hedges self-contained two pass fire tube boiler. The furnace or fire box, which is underneath the cylindrical portion of the boiler, is formed by a metallic jacket lined with fire brick. The flames and hot gases pass from the furnace back through a nest of 4-inch tubes to the combustion chamber at the rear end, thence upward, passing back again to the front end of the boiler through a series of 3-inch tubes, to the smoke stack. The lower portion at the rear of the boiler affords a large settling chamber for the precipitation of all impurities, such impurities being away from the direct heat of the boiler, making the boiler especially adapted for service where the water is heavily charged with mineral substances. It is accessible for cleaning both externally and internally.

Extended Shell Tri-pass Fire Tube Boilers.—The object in this arrangement is to obtain an extra long path over the heating surface for the hot gases, so that the water will absorb a greater percentage of the heat, thus increasing the efficiency.

As shown in the diagram figure 3,744 the hot gases pass from the furnace and flow along the lower portion of the shell, thence

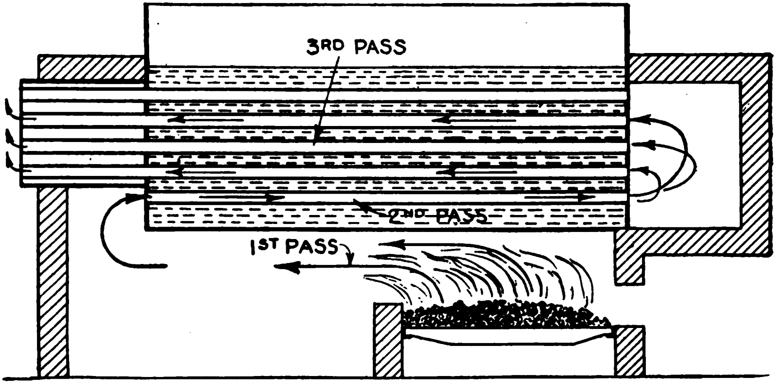


FIG. 3,744.—Diagram showing flow of the hot gases in the extended shell tri-pass fire tube boiler.

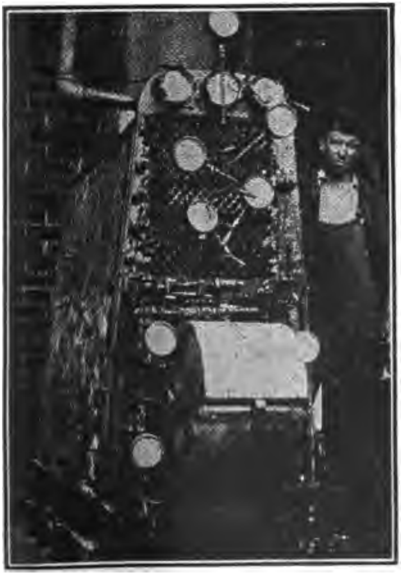


FIG. 3,745.—Talbot 150 horse power contra flow water tube boiler being tested to determine resistance in the various stages due to circulation. ***The boiler consists of*** a combination of fuel economizer, water heater, boiler and steam superheater. The entire unit is made up of small tubes and a honey combed header into which the tubes are secured. Test pressure 1,000 lbs.; superheater adjusted for temperatures up to 800° Fahr. It is claimed that the rapid circulation prevents scaling of tubes. The Talbot boiler is further illustrated and described on pages 2,085 and 2,098.

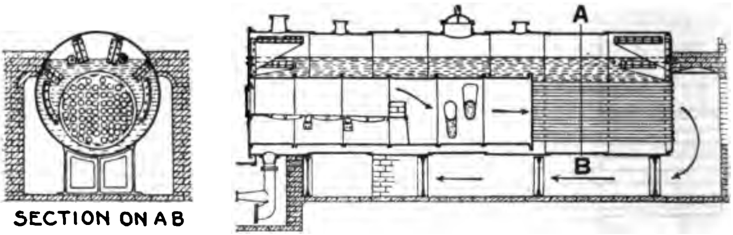
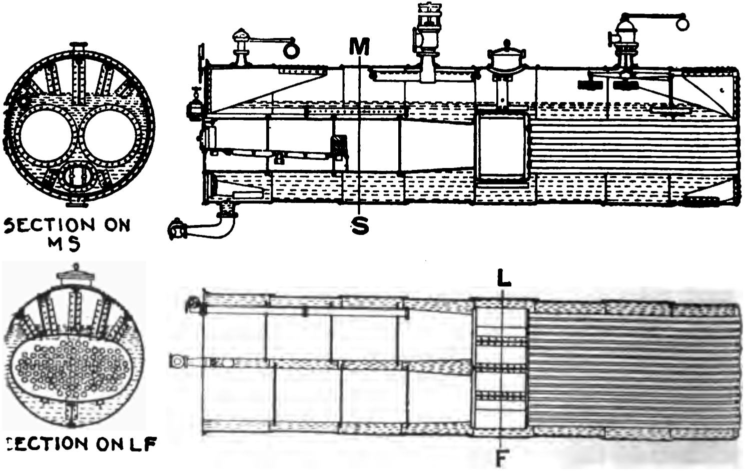


Fig. 3,746 and 3,747.—Cornish single flue, fire tube boiler.



Figs. 3,748 to 3,751.—Lancashire boiler with fire tubes. **Fig. 3748, section on line MS; fig. 3,749, elevation; fig. 3,750, section on line LF; fig. 3,761, plan.**

NOTE.—***Forms of boiler used in different countries.*** The "power of suggestion" or local practise of others (no matter how faulty) enters largely into the selection of a boiler. The following figures by *Hiller* of the National Boiler Insurance Co. of Manchester, Eng., show how largely selection is influenced by local custom.

Per Cent of Boilers of Various Types Used in Europe

	United Kingdom.	France.	Germany.	Switzer land.	Austria.
Lancashire and similar types	38.0	4.7	35.7	19.6	*
Cornish and similar types	23.7	8.2	15.3	40.8	*
Externally fired cylindrical	†6.8	57.3	14.8	15.5	41.0
Externally fired multitubular	....	13.4	5.2	3.5	7.5
Locomotive	11.0	5.1	17.3	5.7	10.5
Small vertical	16.6	3.6	5.0	13.5	6.1
Water tube	1.8	5.7	4.6	1.4	3.8
Other types	2.1	2.0	2.1	....	1.4

* Lancashire, Cornish, and similar types, 29.7. † Including "elephant" boilers.

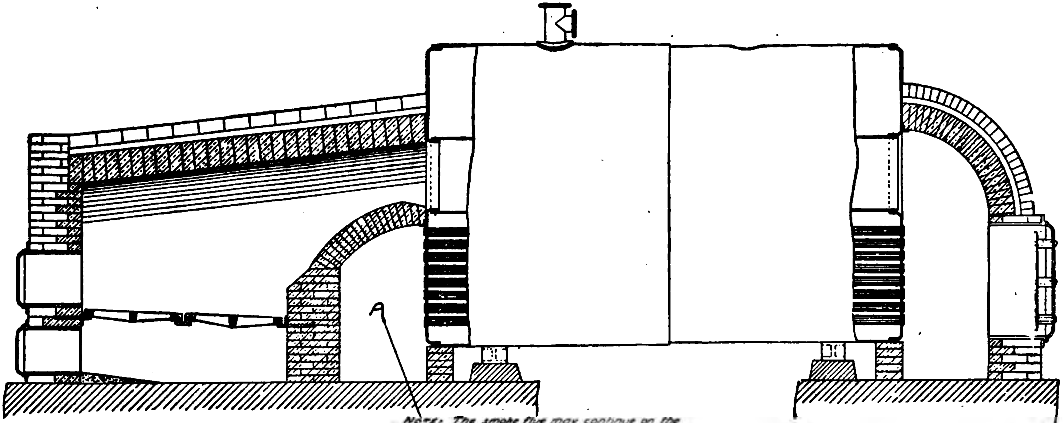
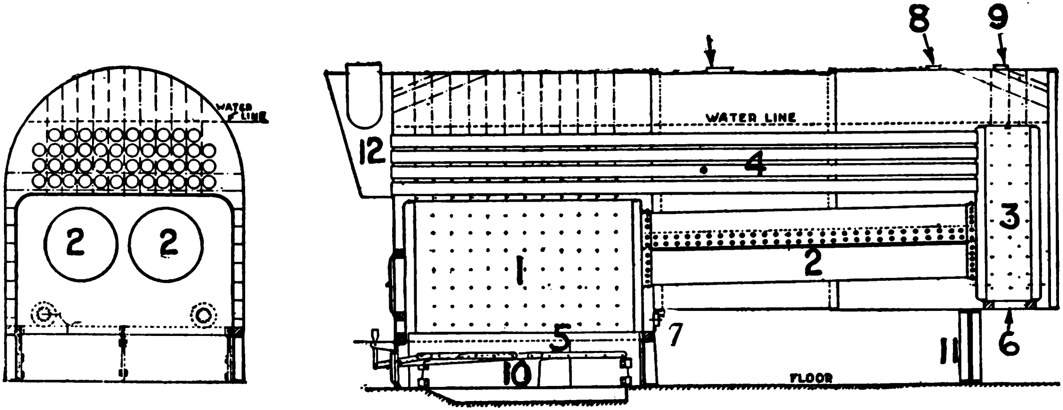

A
NOTE: The smoke flue may continue on the right or left from opening marked "A" to the chimney above the floor if desired, or equally well in an underground flue below the floor if preferred

FIG. 3,725.—Kingsford three flue Lancashire boiler **with** return fire tubes and Dutch oven external furnace. The manufacturer of this boiler contends that the principal heating surface is placed near the surface of the water because most of the steam generated in a two pass boiler is produced by the heating surface of the first pass, the steam thus passing freely and quickly to the surface of the water, and is quickly liberated, thus accelerating the circulation. No doubt the boiler is highly efficient, especially with its Dutch oven furnace, but the setting takes up considerable room, which fact would preclude its use except where plenty of space is available.

Horse Power of Marine and Locomotive Boilers.—The term horse power is not generally used in connection with boilers in marine practice, or with locomotives. The boilers are designed to suit the engines, and are rated by extent of grate and heating surface only.—*Kent.* A boiler horse power is a boiler horse power no matter what be the type of boiler, and there is no good reason why it should not be applied to marine and locomotive boilers.—*Author.*

Grate Surface.—The amount of grate surface required per horse power and the proper ratio of heating surface to grate surface are extremely variable, depending chiefly upon the character of the coal and upon the rate of draught. With good coal, low in ash, approximately equal results may be obtained with large grate surface and light draught and with small grate surface and strong draught, the total amount of coal burned per hour being the same in both cases. With good bituminous coal, like Pittsburgh, low in ash, the best results are obtained with strong draught and high rates of combustion, provided the grate surfaces are cut down so that the total coal burned per hour is not too great for the capacity of the heating surface to absorb the heat produced. With coals high in ash, especially if the ash be easily fusible, tending to choke the grates, large grate surface and a slow rate of combustion are required, unless means, such as shaking grates, are provided to get rid of the ash as fast as it is made.—*Kent,*

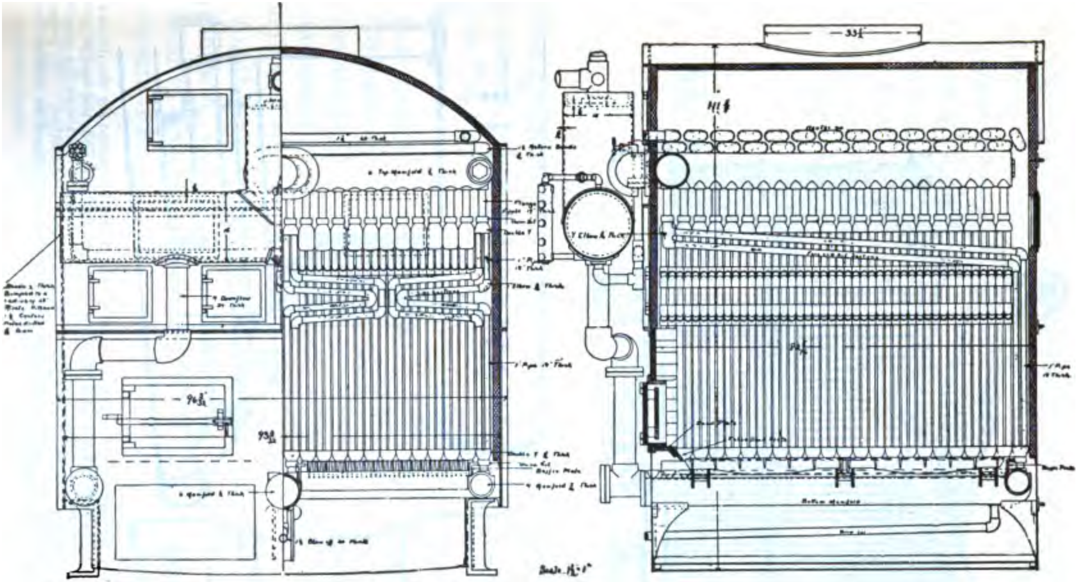


FIGS. 3,753 and 3,754.—Burnham combined flue and fire tube steam heating boiler with internal fire box and Scotch water back. The boiler is low, and is designed to go in shallow cellars where the head room is scant, or where it is difficult to get sufficient depth for a proper gravity return. ***The parts are:*** 1, fire box; 2, flues; 3, combustion chamber; 4, four-inch return tubes; 5, shaking grates; 6, clean out door to combustion chamber; 7, return inlet; 8, tapping for steam main; 9, tapping for safety valve; 10, heavy cast iron ash pit; 11, rear stand; 12, smoke box.

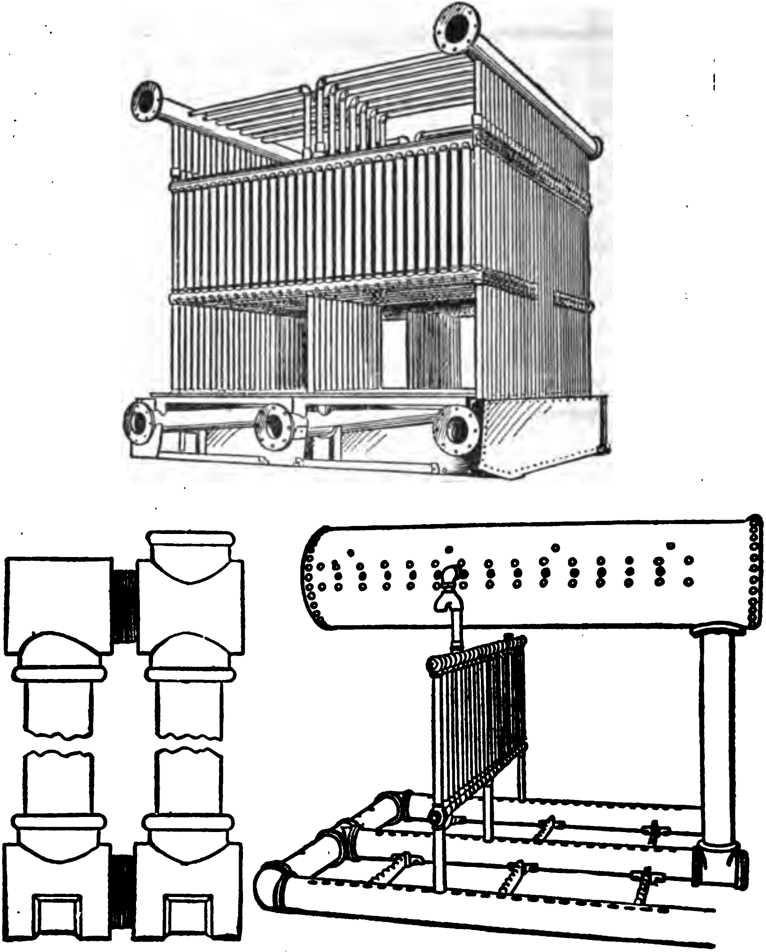
return through the outer rows of tubes, then back and to stack through the central tubes.

2. COMBINED FLUE AND FIRE TUBE BOILERS

Cornish and Lancashire Boilers with Fire Tubes.—Various modifications of the early English boilers have been introduced to overcome the shortcomings of the former.



FIGS. 3,755 and 3,756.—Almy Class E water tube, pipe boiler. ***It consists of*** a large number of pipes screwed into upper and lower manifolds, and is composed of side and fore and aft sections. It also has a feed water heater and steam dome. The top manifold extends across the front and along the sides of the boiler, and the bottom manifold extends along the sides and across the back below the grates. Between these manifolds are the tubes which form the heating surface. Along the front of the boiler extends a drum, which forms a water reservoir connected at the bottom with the lower manifold. At the top it is joined to a steam dome in which the steam rises or separates from the entraned water. The feed enters the feed water header at the top, from whence it passes to the bottom of the horizontal reserve. It then flows through the large tubes into the lower manifold, from which it passes to the tubes, and, becoming heated therein, enters the top manifold, as a mixture of steam and water, flowing to the separator. The water from the separator falls to the bottom of the reservoir and continues in the circulation circuit until evaporated.



FIGS. 3,757 to 3,759.—Tailor pipe boiler. Fig. 3,757 shows the assembly except for the drum as shown in fig. 3,759. The pipes are screwed together as shown in fig. 3,758, the special processes in the making of this joint giving one of great durability. Fig. 3,759 shows the assembly of drum, down flow pipe, bottom or mud pipes and one section in position. The design of these sections is such that the upper and lower headers form in themselves baffles thus giving a two pass flow for the products of combustion.

In order to secure adequate heating surface without an unduly long boiler, the furnace flues instead of running full length have been shortened and connected with fire tubes.

Figures 3,746 and 3,747 show a single flue boiler connected in this manner, and figures 3,748 to 3,751, a two furnace or Lancashire type in which the breeches is shortened, forming a common combustion chamber with its far side connected to a mass of fire tubes.

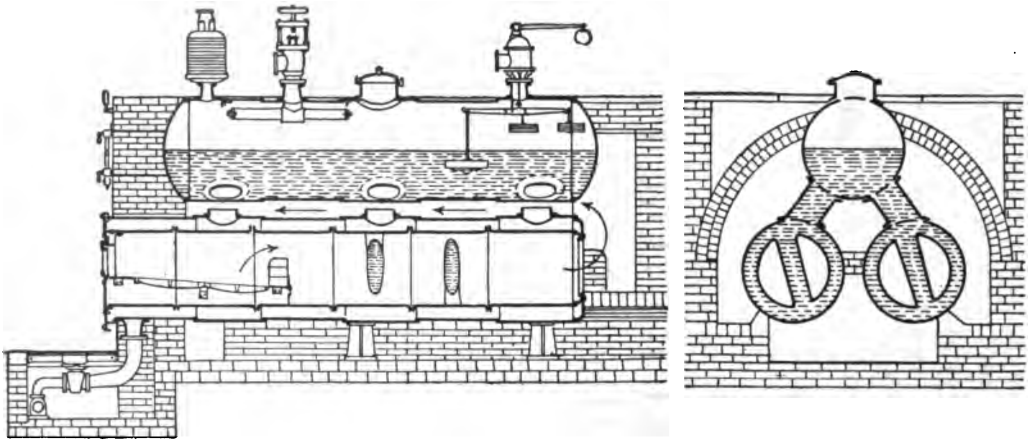
3. WATER TUBE (OR PIPE) BOILERS

The construction of water tube boilers is so varied that the distinction between regular and peculiar forms is not so marked as in the case of fire tube boilers. However, there are a few examples of unusual construction that may be mentioned.

For instance, the Almy boiler, shown in figures 3,755 and 3,756 does not permit of its being classed as either a vertical or horizontal boiler. It is, however, sectional and in its construction some special fittings are employed, the general features being mentioned under the illustrations.

Another peculiar form is the Taylor boiler, which in a way resembles it, in that it is made up of a large number of pipes placed in such positions as to make the assembly distinctively different from the regular types.

The Taylor boiler is *sectional*, being composed of a number of sections consisting of a number of vertical pipes connected *in parallel* by horizontal headers and *in series* with the drum and bottom or mud pipes by vertical connections. The details of construction are shown in figs. 3,757 to 3,759.



FIGS. 3,760 and 3,761.—Fairbain combined flue and water tube boiler. ***In construction*** there are two cylindrical flues which are the furnaces. These flues are pierced by numerous Galloway tubes and are connected by necks to an upper drum, the assembly having a triangular connected form as shown in the end view fig. 3,761.

4. COMBINED FIRE TUBE (OR FLUE) AND WATER TUBE BOILERS

In the combination of fire and water tubes in a boiler may be found numerous instances of peculiar forms that cannot be classed with any of the regular types.

The Fairbain boiler shown in figures 3,760 and 3,761 represents an early attempt to combine internal firing with large water capacity and at the same time without having recourse to shells of large diameter, thus rendering them better adapted to high pressures.

The principal advantage of this design is that it furnishes a large water capacity in a space that would not admit of a Lancashire boiler of full length. As a transition or intermediate type between the fire tube, and combined fire tube and water tube boilers is the fire tube boiler with water grate as used in the down draught system of combustion. While the water tubes serve primarily as grate bars, they form a very efficient heating surface and may be considered as such in the classification. Fig. 3,762 is an example of this type.

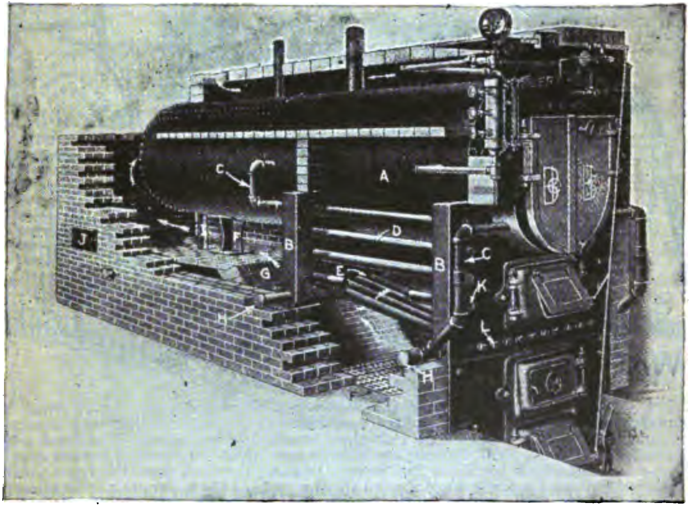


Fig. 3,762.—Herbert fire tube boiler with water tube down draught grate. ***The parts are:*** A, fire tube boiler; B, water legs; C, circulating pipes; D, side tubes connecting water legs; E, water tube grate; F, lower shaking grate; G, fire-brick bridge-wall; H, clean-out plugs; K-L, brass clean-out plugs.

In operation the flames travel downward through the water tube grate E, placed the same as the ordinary grate, and on which the coal is fired. This grate is piped up with the boiler, and water circulates through it and the piping.

A short distance under the water tube grate a second common grate is placed, on which the spent fuel falls as it burns and as the upper fire is worked. Between these two grates is a furnace of high temperature in which the fuel, both solid and gaseous, is consumed before passing to the boiler. It will be seen that the conditions for the entire combustion of the coal are thus fully met.

The heat of the gases is made available, thereby saving fuel, while heating surface is added to the boiler and its natural circulation improved.

In the Lyons combined fire tube and water tube boiler, figure 3,763, the water tubes are inserted for a different purpose, namely, 1, to improve the circulation, 2, to protect the shell from the direct action of the fire, and 3, by aid of tiles, to prevent the gases of combustion coming in contact with the colder surfaces of the tubes until complete oxidation, thus obtaining a sort of Dutch oven furnace effect.

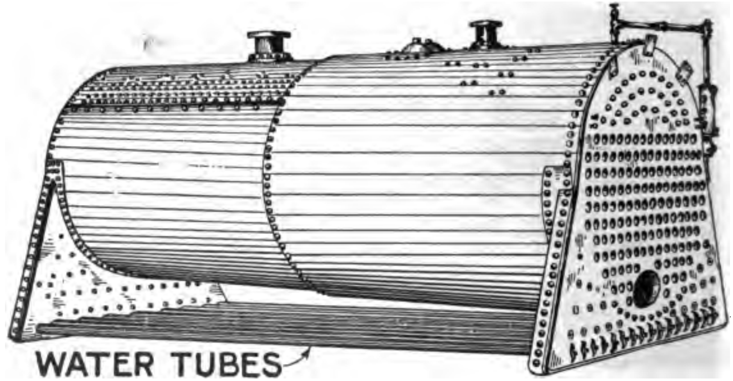


FIG. 3,763.—Lyons combined fire tube and water tube boiler with one row of water tubes. *In construction* the boiler consists of two main sections: the upper or shell with its contained fire tubes, and the lower or saddles with their attached water tubes. The front and rear heads extend below the shell, forming the saddles into which the water tubes are expanded. The rear saddle extends twelve inches farther beneath the shell than the front saddle, so that the water tubes incline upward toward the front end of the boiler, this inclination allowing the water to be freely carried to the front end of the boiler and discharged through the front saddle into the shell. The shell plates are cut away at the point of junction with the saddles, thus giving a free and unobstructed path for the water in its circulation. There are hand holes in both heads. Tile is suspended from the water tubes directly above the grate by transverse rods resting on the top of the tubes.

A further development of this style boiler is shown in figure 3,764, which has two instead of one row of water tubes connecting to manifolds or headers at the ends of the boiler.

The cut shows plainly both the fire and water tubes. Pile baffles are placed above each row of water tubes giving the hot gases a tri-pass flow from the furnace to the chimney.

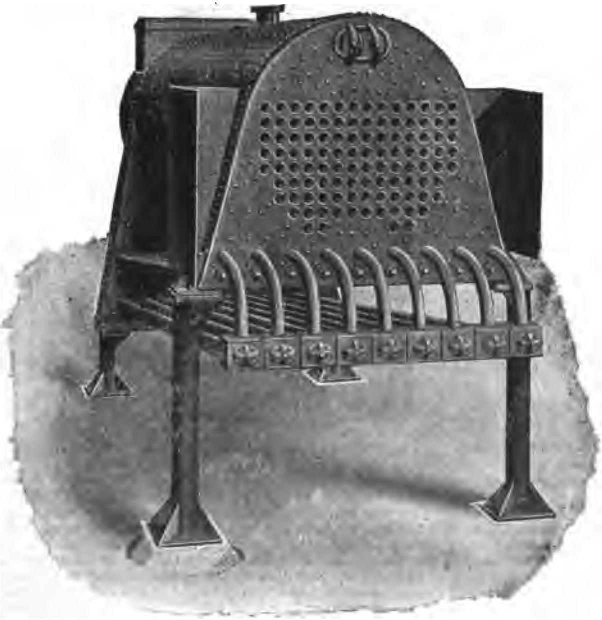


FIG. 3,764.—Hawkes combined fire tube and water tube boiler with *two* rows of water tubes.

5. COMBINED SHELL AND WATER TUBE BOILERS

This is a favorite combination used in the design of fire engine

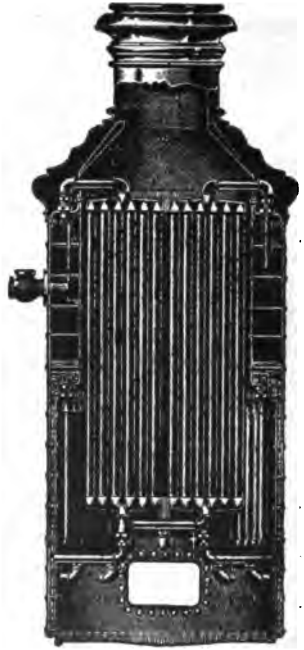
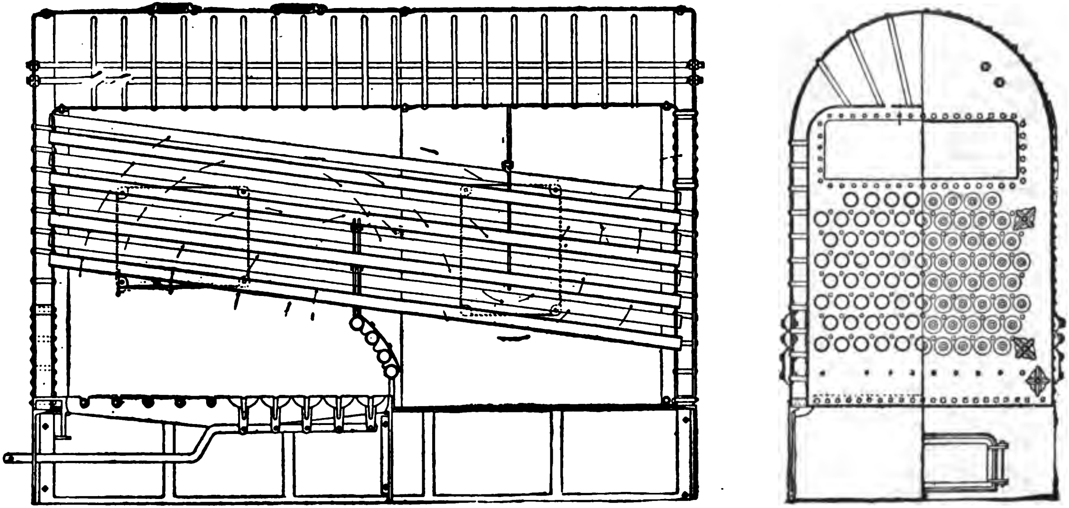


FIG. 3,765.—Fox combined shell and water tube fire engine boiler. ***It consists of*** a simple annular shell heavily stay-bolted throughout, and constitutes a water legged fire box and steam reservoir; the principal heating surface of the boiler consists of an ***outer*** and an ***inner tube system***. The *outer system* embraces the short manifold sections which completely encircle the fire-box walls. The top end of each section is screwed and suspended from the flanged part of the shell, and the lower end is stayed by direct connection with the leg of the fire-box. *The tubes are "staggered"* in their manifolds, thereby exposing the greatest possible surface to the fire, and filling out the space due to the difference in the width of the water-leg and steam space of the shell. The direct application of heat to the tubes causes a natural and active upward current therein, which in turn induces a corresponding downward movement of the water in the leg of the fire box, and promotes the flow into the feed pipes. The inner tube system comprises those tube sections which extend to the upper limits of the boiler, their number and arrangement being such as to completely fill the interior of the shell above the space required for the combustion of the fuel. The construction of the vertical inner tube system is simple, and consists of the required number of manifold sections, suitably arranged to conform to the circular space occupied, the flat inner end of each upper manifold being rigidly bolted to a heavy transverse beam, which in turn is supported in suitable pockets secured to the upper part of the shell. At the top of the boiler, each section has its own connection with the steam space, and it is easy to remove either one of the sections separately without disturbing the others; *or the entire inner tube system can be raised out of the boiler as a whole, after breaking the proper connections*, all of which are accessible. The current of steam and water carried over through the top connections of the inner system is generally sufficient to keep the tubes clear of scale; and the point of discharge and disengagement is brought down low, to prevent its mixture with the drier steam contained in the highest part of the shell.



FIGS. 3,766 and 3,767.—Harrisburg combined shell and water tube boiler for heating and power service.

boilers. One type of boiler used for this purpose is shown in figure 3,765, the construction is plainly illustrated and described under the cut.

Figures 3,766 to 3,767 show a boiler with box shaped shell enclosing water tubes and internally fired furnace.

A further development of the type is shown in figure 3,768, which is provided with a water tube down draught grate in addition to the main water tube heating surface.

6. COMBINED SHELL, FIRE AND WATER TUBE BOILERS

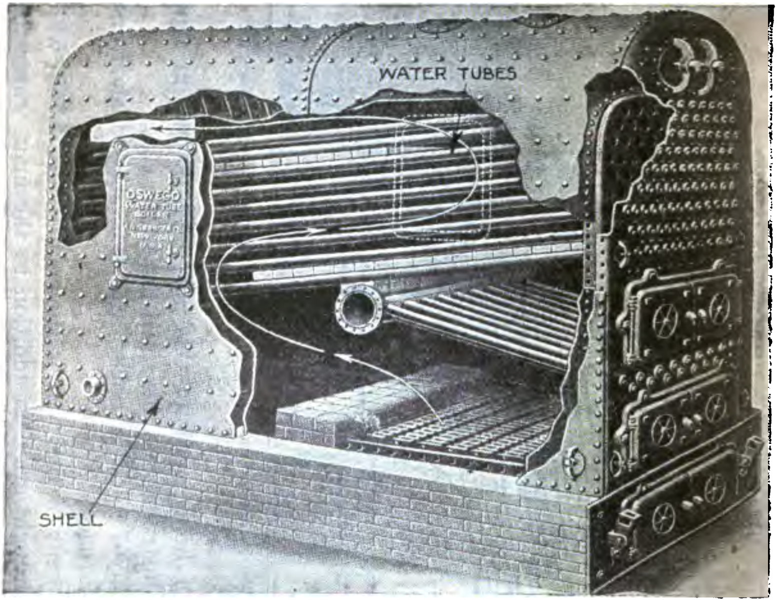
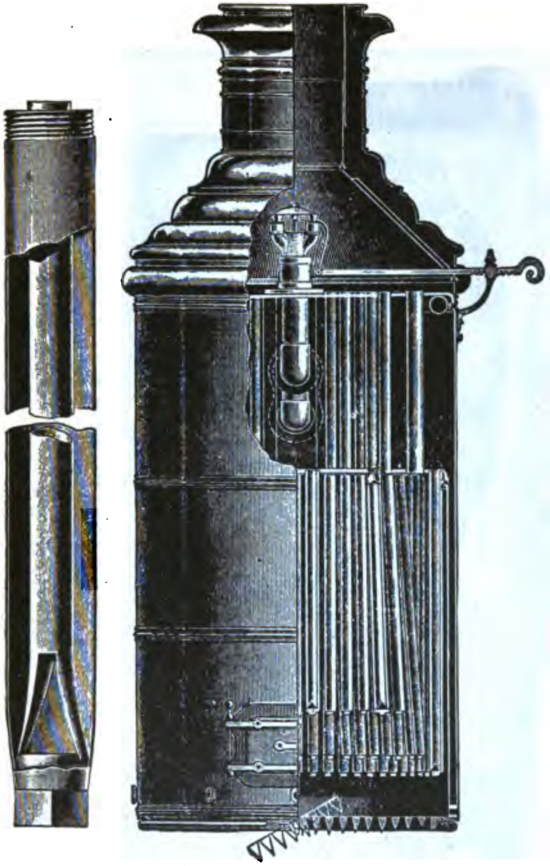


Fig. 3,768.—Oswego combined shell and water tube boiler with water tube down draught grate.

A boiler combining the features of shell, fire tubes, Field drop tubes, and water grate is shown in figure 3,771 used for steam heating. This represents a very unusual combination of features employed in boiler design and it is the only one embodying these various items that has come to the notice of the author.



FIGS. 3,769 and 3,770.—Silsby combined fire tube and (Field drop) water tube fire engine boiler, and detail (enlarged) of the Field drop tube. ***In construction,*** the fire box has a series of circulating water tubes arranged in concentric circles and securely screwed into the crown sheet. These drop tubes are closed at their lower ends by means of wrought iron plugs welded in, and within each of them is placed a much smaller and thinner tube, which latter is open at both ends. The cooler water in the boiler descends through the inner tube and is thus brought directly into the hottest part of the furnace, whence, after being for the most part converted into steam, it ascends through the annular spaces between these inner and outer tubes. The gases of combustion pass from the fire box to the stack through fire tubes, the lower ends of which are expanded into the crown sheet, and the upper ends into the top head of the boiler.

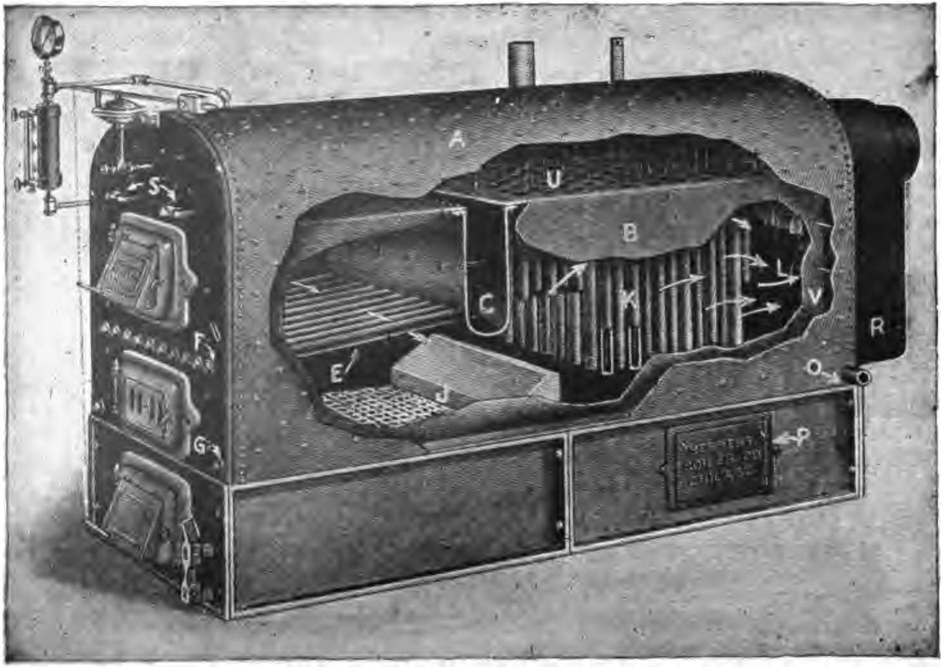


FIG. 3,771.—Herbert combined shell, fire and Field drop water tube boiler with down draught water grate. ***The parts are:*** A, outer shell; B, inner shell; C, water connection for water grate; E, water grate; F, water grate tube plugs; G, lower plug; J, grate wall; K, Field drop tubes; L, fire tube exit to stack; O, feed connection; P, door; R, slack connection; S, hand holes; U, tube sheet; V, water space between outer and inner shell.

CHAPTER 67

STEAM HEATING BOILERS

The conditions under which a boiler works in furnishing steam for heating buildings are quite different from those encountered in a power plant, hence, as might be expected, the construction of a heating boiler is quite unlike that of a power boiler.

The chief points to be considered in design are:

1. Very low steam pressure;
2. Low rate of combustion;
3. Long intervals between firing;
4. Automatic draught control;
5. ***Adequate*** *heating surface.*

Accordingly the construction need not be so substantial to resist internal pressure, as for power boilers, thus permitting the use of cast iron.

Most heating boilers are built in sections of cast iron making a very durable construction.

By building up a boiler from cast iron sections, the size may be varied considerably according to the number of sections used, thus a multiplicity of sizes is obtained without requiring numerous patterns. While this reduces the cost of manufacture, it results in numerous instances of boilers not properly proportioned for economy, especially in the vertical types.

25:1

The Heating Surface.—The author after a laborious examination of about one hundred boiler catalogues found that while nearly all gave the grate area, very few gave the area of heating surface (for obvious reasons).

While, for example, he found that in one size of the Vance boiler 38 square feet of heating surface per square feet of grate is provided, in another make boiler (the name ought to be printed in large letters) only 8.3 square feet of heating surface is provided per square foot of grate. Of course, if coal cost nothing, or the coal dealers paid for the privilege of delivering it to your door, such allowance of heating surface might suffice, ***but***

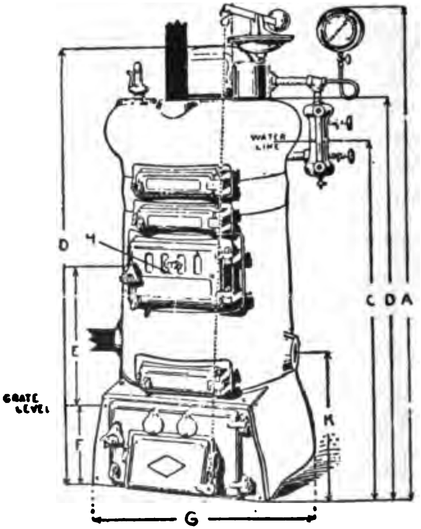


FIG. 3,772.—Typical round vertical boiler showing general exterior appearance and fixtures.

where there is any regard for economy an ***adequate amount*** *of heating surface will be provided.*

If, instead of closing public buildings, or ordering lightless nights to conserve the fuel supply, the authorities would prohibit the manufacture of such wasteful apparatus as mentioned above, a much more intelligent solution of the fuel problem would be arrived at, and without inconvenience and annoyance of the public. Although the low rate of combustion in a heating boiler permits a lower ratio of heating surface to grate area no such ridiculous ratio as 8.3 to 1 should be used.

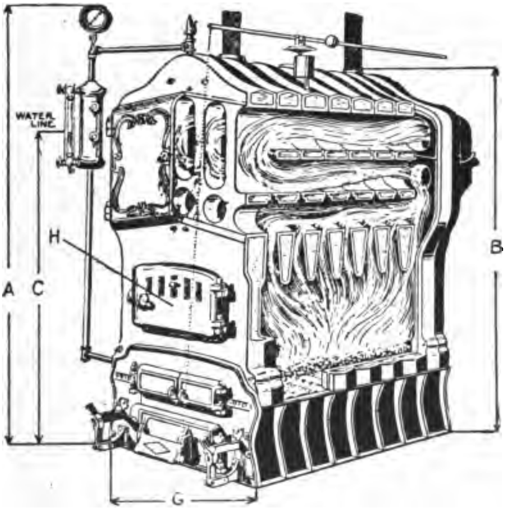
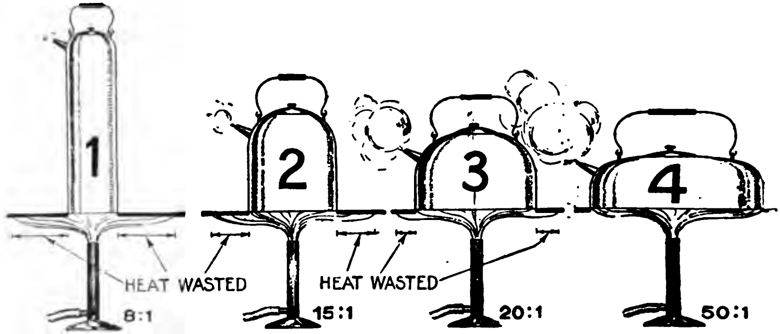


FIG. 3,773.—Sectional view of typical horizontal boiler showing sections and passages for the flow of the hot gases.

The usual construction of a vertical sectional boiler comprises a base section containing the grate, a fire pot with space all around for the water, and piled up on top of this is one or more



FIGS. 3,774 to 3,777.—Effect of inadequate heating surface. This may be illustrated by taking several kitchen hot water kettles of equal capacity, but of different diameters, so that the area of the bottom or part exposed to the fire (heating surface) will say 8, 15, 20, and 25 square inches. Put the same quantity of water into each and place under each a bunsen burner whose tip has an area of 1 square inch. When the burners are lit (assuming equal flames) it will be noticed that only a very small portion of the flame will touch the bottom of kettle No. 1, more will come in contact with No. 2, still more with No. 3, and all with No. 4. The result is that No. 4 will begin to boil first, No. 3 next, then No. 2, and last No. 1. Evidently it takes less fuel to heat No. 4 than any of the others, the waste being about in the proportion indicated by the arrows. *The same thing happens in a house heating boiler.* Don't blame the manufacturers because there are a lot of boilers like kettles Nos. 1 and 2 on the market—*it's your fault.* If you thought less about first cost, and more about your coal bills you would buy a boiler like No. 4 kettle, and the cost of coal wouldn't be so high.

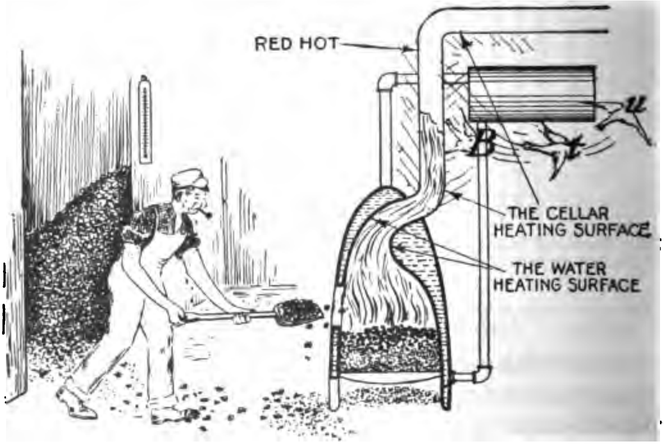
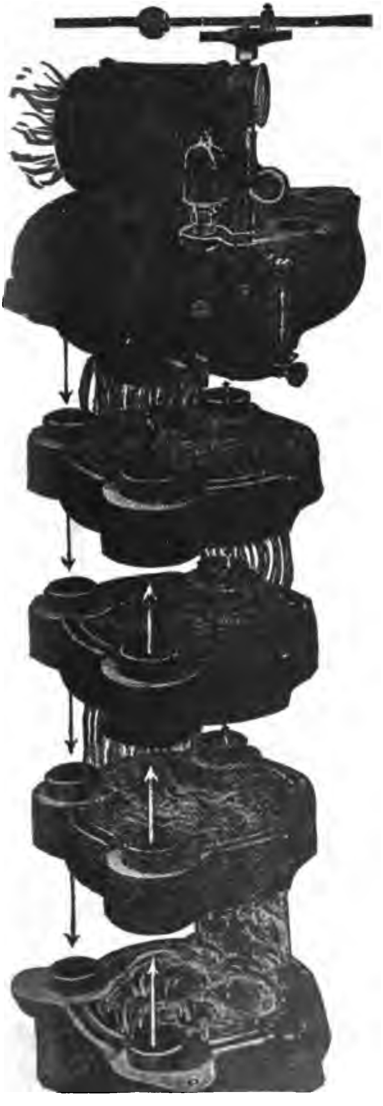


FIG. 3,778.—The principal reason why the tenants get no hot water. It's not the fault of the manufacturer, he simply builds what the public is willing to pay for and does not worry about the coal bills.



intermediate "sections," and a top or dome, thus several sizes of boilers are listed all having the same size grate.

Evidently the efficiency of such apparatus will depend principally upon the number of sections or amount of heating surface piled up over the furnace and the arrangement of these sections. Accordingly if the purchaser be interested in economy of fuel, he will select a boiler which has an adequate amount of heating surface in proportion to the grate area, and especially in view of the ever increasing cost of fuel the ratio of heating surface to grate area should not be less than 25 to 1.

Rate of Combustion.—In steam boilers for power plants which receive constant attention, coal is generally burned at from 10 to 30 pounds per square foot of grate per hour. However, in heating boilers, the conditions are different. There is no fireman in constant attendance, the practice being to dump on the grate a considerable quantity of coal sufficient to last 6 to 8 hours at a low rate of combustion. This requires a deep fire pot to hold the considerable depth of fuel.

FIG. 3,779.—International boiler parts showing circulation and travel of the hot gases.

For house heating boilers the standard combustion rate is taken at 4 pounds of coal per square foot of grate per hour, but for larger boilers such as used for large buildings where the firing is done more frequently the grates are proportioned for a higher rate.

According to the American Society of Heating and Ventilation Engineers: "The grate surface to be provided depends on the rate of combustion and this, in turn, on the attendance and draught, and on the size of the boiler. Small boilers are usually adapted for intermittent attention and a slow rate of combustion. The larger the boiler the more attention is given to it and the more heating surface is provided per square foot of grate."

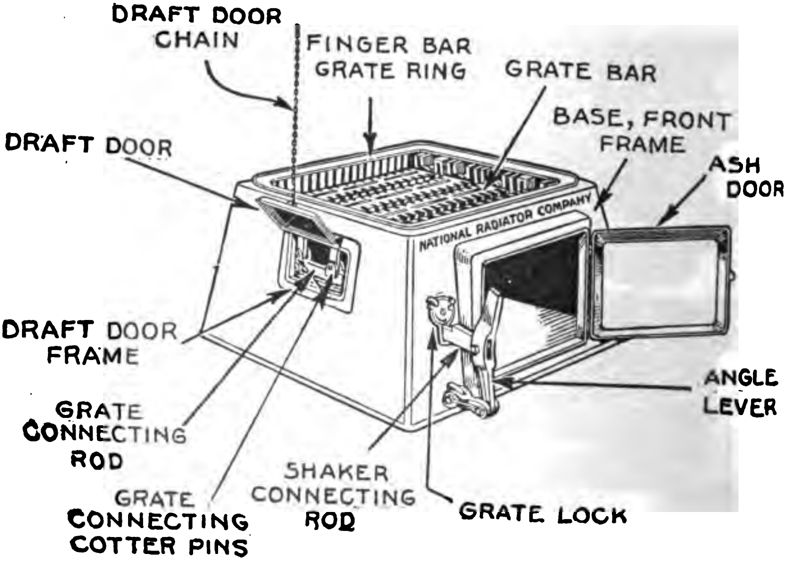


Fig. 3,780.—National square base with names of parts.

"The following rates of combustion are common for internally fired heating boilers":

Sq. ft. of grate....................	4 to 8	10 to 18	20 to 30
Lbs. coal per sq. ft. of grate per hour	4	6	10

The following table from Kent gives some proportions and results that should be obtained:

Proportions and Performance of Heating Boilers

	Low boiler	Medium boiler	High boiler
1 square foot of grate should burn.....	3	4	5 pounds coal per hour
" " " " " " develop..	30,000	40,000	50,000 *B.t.u.* per hour
" " " " " ***will require....***	***15***	***20***	***25 square feet heating surface***
" " " " " " supply.....	120	160	200 square feet radiating surface

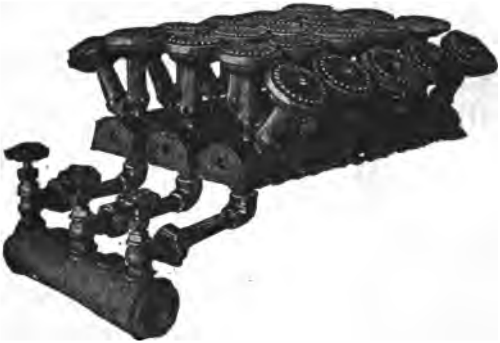


FIG. 3,781.—Gas burner and manifolds for square fire pots. The burners are mounted complete with air mixers and orifice spuds. ***In installing,*** the burners are placed on top the grate bars and gas connection made through the grate bars and out through ash pit.

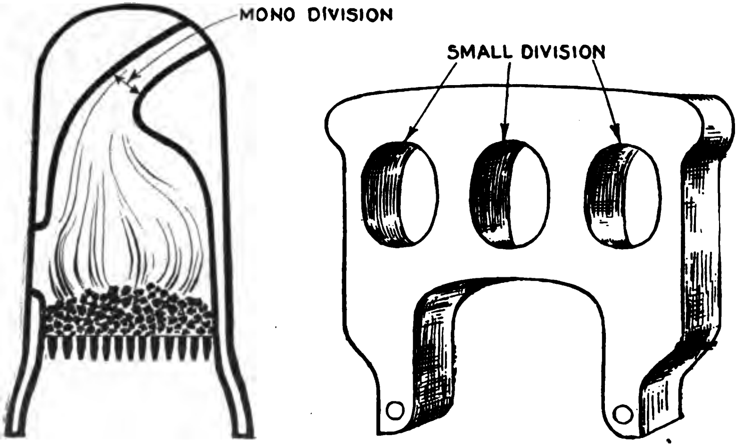
Points on Boilers.—In the selection of a boiler it is well to examine closely the details of construction. A good design should embrace the following features:

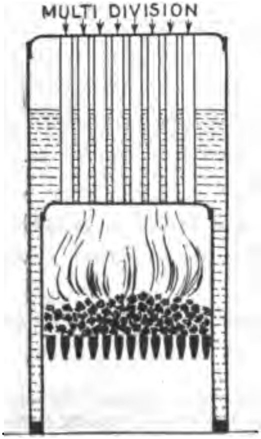
1. There should be ***not less** than **25** square feet of heating surface per square foot of grate area.*

If manufacturers would stop talking so much about "prime" or direct and indirect heating surface, and state the total amount of heating surface provided per square foot of grate, and its arrangement, the purchaser

would be more enlightened, especially the better informed, and less printer's ink and paper would be wasted.

2. The passages through which the hot gases traverse the heating surface should be so arranged that they have the proper length of travel (guided by baffles or equivalent) and come in contact with all the heating surface, that is, short circuiting should be avoided.

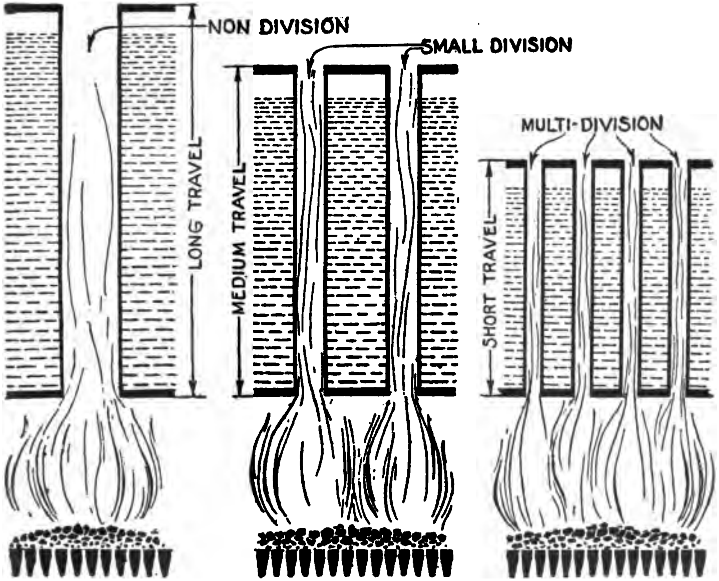




The proper length of travel will depend on the *arrangement* of the heating surface. There are

Figs. 3,782 to 3,784.—Division of the hot gases. For equal travel of the gases over the heating surface the *mono-divisional arrangement of fig. 3,782 is very wasteful.* As the gases are split up into more divisions as in figs. 3,783 and 3,784 each being surrounded by heating surfaces, evidently (assuming adequate combustion chamber) more heat is absorbed and the stack temperature reduced, because the gases come into contact with a larger amount of heating surface per foot of travel. It follows then that *the less the division of the gases, the longer must be the travel of the gases,* for equal efficiency.

three cases, 1, ***non-division***, small division, and ***multi-division*** of the gases, as shown in figs. 3,785 to 3,787. Evidently the first arrangement requires numeruos passes for the gas to travel for proper absorption of heat, whereas with the second or third arrangement a short travel will suffice, the length of travel depending on the degree of division of the gases as shown in the figures.



FIGS. 3,785 to 3,787.—The efficiency of the heating surface does not depend on the length of travel, but on the ratio of the cross sectional area of the passage to its length and the arrangement or disposition of the surface with respect to the hot gases. In a vertical tubular boiler for instance there may be only one large and long tube as in fig. 3,785, and the temperature of the gases escaping at the end of the tube will assume a certain value depending upon the rate of combustion and the efficiency will depend on these values. The single tube of fig. 3,785 may be replaced by several smaller and shorter tubes as in fig. 3,786, or a still larger number of very small and very short tubes as in fig. 3,787, the ratio of length to diameter (or cross sectional area) being the same in each case, and there will not be any loss of efficiency. That is by properly proportioning the size and number of the tubes. Any length tube may be used without increasing the stack temperature.

3. For a given length of travel of the hot gases the efficiency of the heating surface decreases with the number of turns, as in figures 3,788 and 3,789.

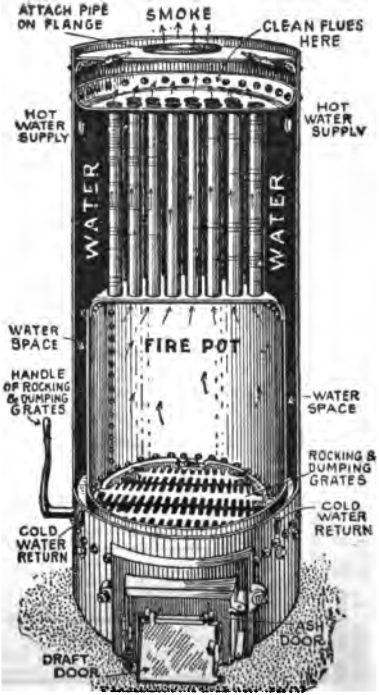
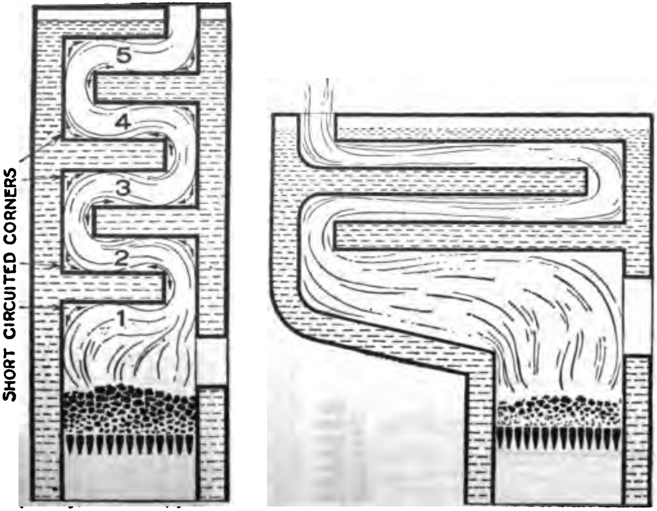
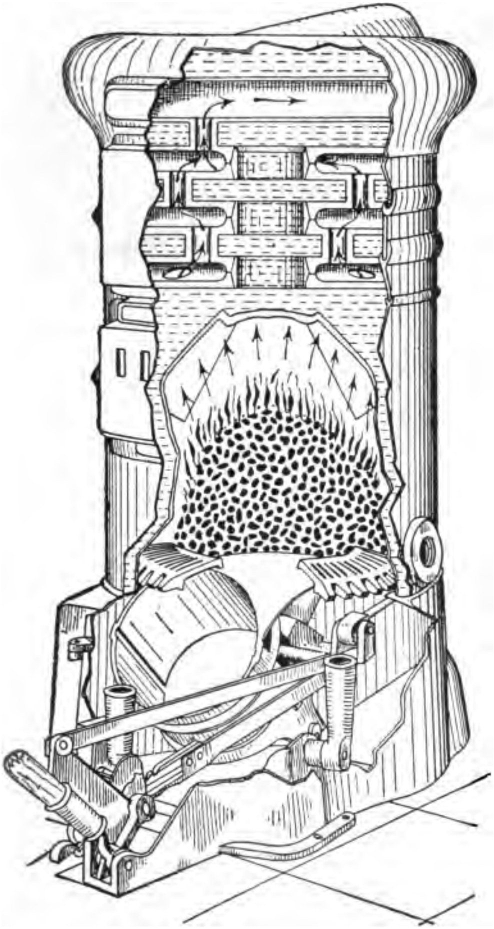


FIG. 3,790.—Andrews vertical tubular boiler; an example of ***multi-division*** of the hot gases giving a very effective form of heating surface.



FIGS. 3,788 and 3,789.—Characteristics of short and long pass boilers. For a given travel of the hot gases the shorter the passes the greater the number of turns where short circuiting occurs, hence the greater the proportion of the heating surface rendered inefficient. Accordingly for equal travel, ***a few long passes are more efficient than many short passes.***



Whenever the direction of flow is changed, centrifugal force causes the steam of hot gases to leave one surface and pile up on the other, short circuiting the abrupt corners.

4. The combustion chamber or fire pot should be large so as to obtain good combustion.

This involves for equal grate areas, and equal intervals between firings, a larger fire pot for high than for low combustion rates, in order to provide space for the larger charge of fuel at each firing.

5. The fire box should be proportioned according to the rate of combustion, and in the smaller sizes should have considerable depth below the fire door in order to hold sufficient charge for from 6 to 8 hours operation without attention.

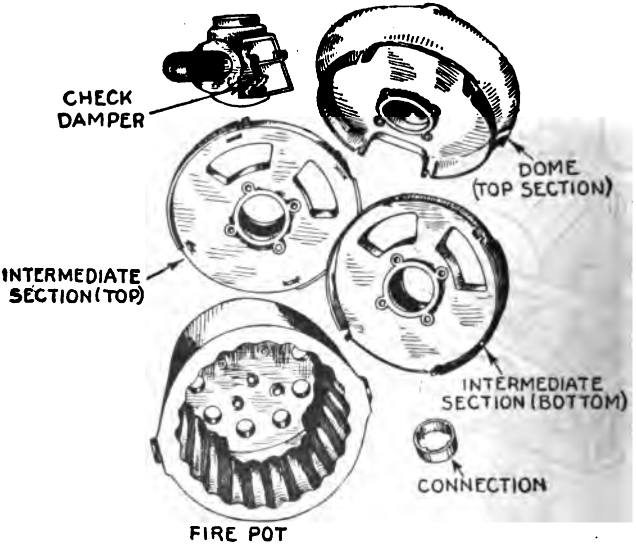
Fig. 3,791.—Williamson underfeed boiler. ***In construction,*** there is connecting with the coal chute a funnel shaped hopper, with its feed opening outside of the boiler proper. By means of a piston, which slides in this coal chute, and a light, wooden lever, which operates the plunger, coal which has been placed in the hopper is easily pumped through the chute, up onto the grate and underneath the body of burning coal. The fire is pushed upward and outward, and the fresh coal is thus surrounded on all sides and the top by fire.

3 LB. RATE

4 LB. RATE

5 LB. RATE

FIGS. 3,792 to 3,794.—The depth of the fire pot should increase with the rate of combustion in order not to reduce the size of the combustion chamber. The figures show the relative amounts of coal thrown into the furnace at each firing for the 3-, 4- and 5- pound combustion rates with equal intervals between firings and equal grate area. Hence, *for different ratings on one size grate, the* ***higher*** *the rating the* ***deeper*** *should the fire pot be, to avoid decreasing the size of the combustion chamber.*



FIGS. 3,795 to 3,800.—Parts of Magee boiler above the base showing fire pot intermediate sections, dome, damper, and push nipple. ***In construction,*** the corner sheet is cast integral with the fire pot whose interior sides are corrugated to increase the heating surface. The parts are joined together by push nipples.

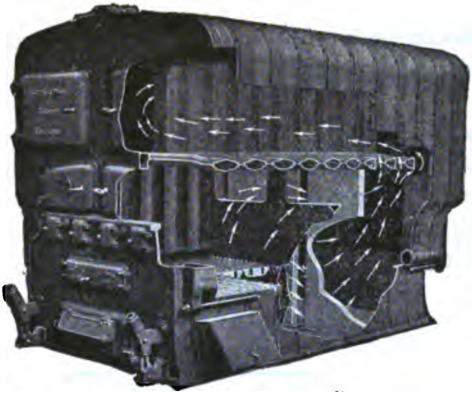


FIG. 3,801.—United States "Capitol" horizontal boiler showing mixing chamber and ignition wall. ***In operation,*** the volatile gases pass from the furnace into a mixing chamber through two horizontal openings at the top and in the back or bridge wall of the furnace. This mixing chamber back of the furnace is formed by the bridge wall at the front and an ignition wall of fire brick at the rear of the mixing chamber. Because of the continuous volume of burning gases pouring from the furnace through the bridge wall and against this ignition wall it is constantly maintained at a temperature of approximately 1,600 degrees or about 400 degrees above the ignition point, the temperature at which these gases burn. All the gases from the furnace must pass through this mixing chamber, and while they enter the mixing chamber through two horizontal openings, their escape from the mixing chamber to the combustion chamber at the rear of the boiler is through a long vertical opening in the ignition wall, the area of which is slightly less than the area of the two horizontal openings into the mixing chamber. It is claimed that the effect of this arrangement is a congestion and intermixture of burning gases within the mixing chamber in contact constantly with the ignition wall, which is maintained at a temperature above the ignition point of the gases.

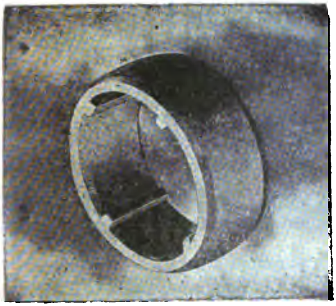


FIG. 3,802.—Push nipple used to join together sections of cast iron boilers. The nipple is accurately machined and has a slight taper so that when forced into the opening in the sections, by drawing the sections together by means of a rod a tight joint is obtained.

FIG. 3,803.—Gilt edge water back attachment for hot water supply.

6. There should be a wide door at the level of the grate and just high enough to permit removing clinkers; it is called the slice door.

7. The grate should be of the shaking and dumping type, easily accessible for repairs, and of a standard make so that duplicate parts may be obtained.

8. The ash pit should be large and *deep* so that it will hold a large quantity of ashes.

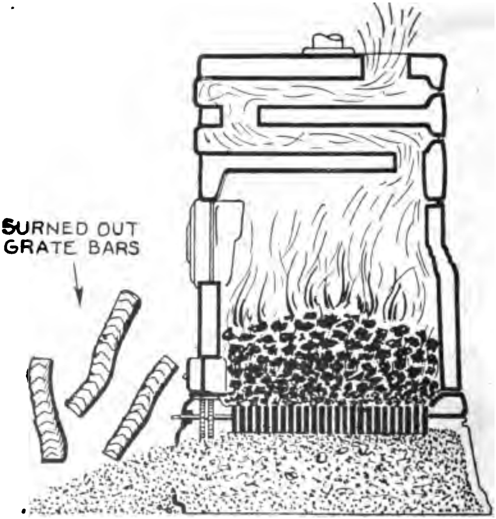


FIG. 3,804.—Usual condition of the ash pit when the owner cannot put off taking up the ashes any longer. Note the burned out grate bars due to letting ashes accumulate in the ash pit. The illustration does not show the new grate just ordered from the plumber, but it is on the way.

With the inferior and careless attention (or rather non-attention) usually given to house heating boilers, ashes are allowed to accumulate until they are flush with the grate bars and are then only removed because they interfere with the draught. Of course, where the owner does his own firing and can stand the expense of frequent grate renewals, he may adopt this method of handling the ashes.

8. There should be a positive circulation of water and sufficient liberating surface and steam space provided to prevent priming or unsteady water level.

9. The ratings of heating boilers as given in manufacturers' catalogues may be as a rule safely accepted, but the efficiency of the apparatus should be seriously questioned.

The ***amount*** *and* ***arrangement*** *of the heating surface,* ***size*** *of combustion chamber and* ***grate area*** *should be thoroughly investigated.*

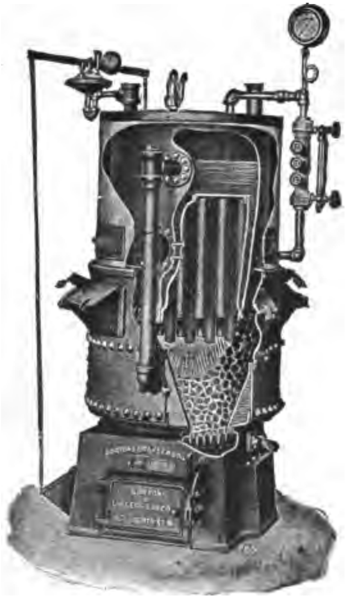
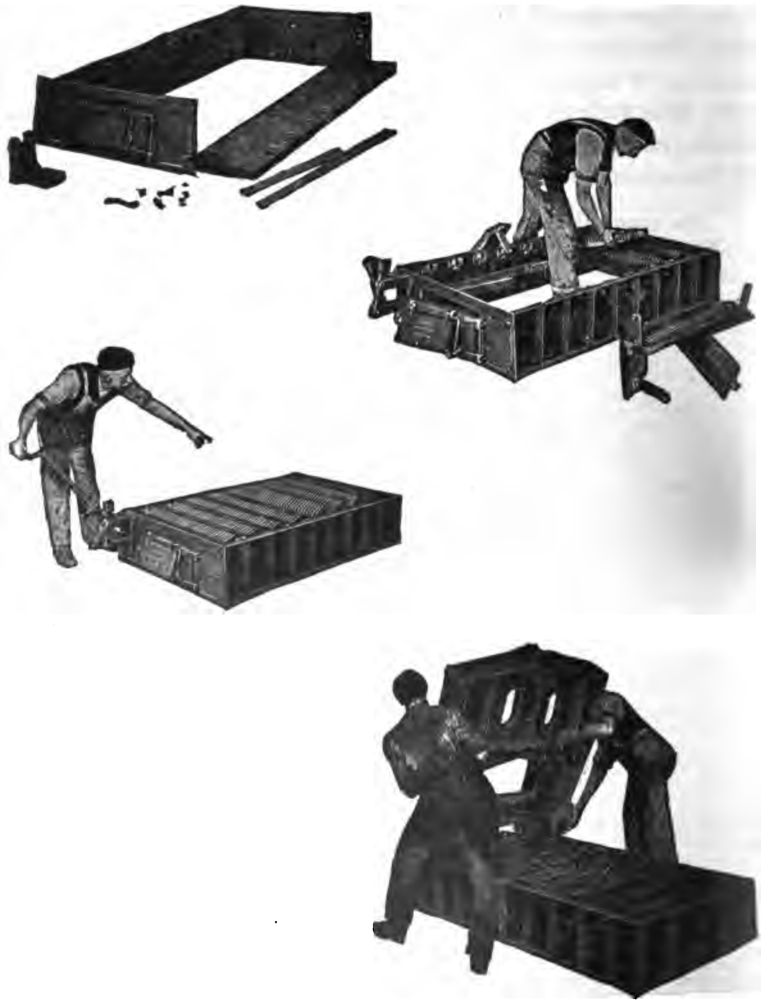
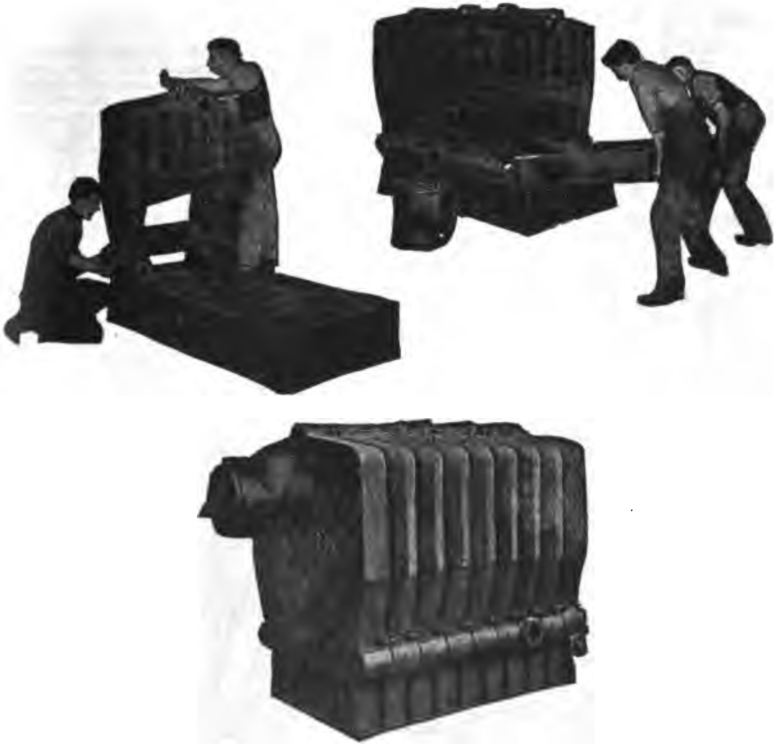


FIG. 3,805.—Gorton drop tube magazine feed vertical boiler, designed especially for soft coal. ***In construction,*** the boiler is made in two parts, the tubular part, or boiler shell, is directly over the fire, and the lower part, or the water leg, surrounds the fire. They are connected together by the two circulation pipes, one in the front and one in the back of the boiler. The lower part of the shell extends down into the upper part of the water leg, and the space between the shell and the water leg is used for the coal reservoir and coking chambers. The reservoir is divided into four compartments, which form the coking chambers, in which the coal is coked. The fire pot is so constructed that sufficient additional air is drawn through the ring at the lower edge of the coking chambers to ignite the gases arising from the coking process, giving good combustion.



FIGS. 3,806 to 3,812.—Method of assembling a horizontal boiler. First comes the base, fig. 3,806. It is in four main pieces which are bolted together; fig. 3,807, the grate bars are dropped into their sockets; fig. 3,808, after fastening grate shaker connections, the grate is tested

Construction Details.—A large proportion of the small and medium size boilers are made of cast iron. This material not only being very durable, but lends itself to flexibility of design, the sectional method of construction permitting boilers to be shipped knocked down and carried through narrow openings in buildings.



FIGS. 3,806 to 3,812.—*Continued.*

by shaking, the back half is being operated fig. 3,808; the first section is lifted on and slid into place fig. 3,809; push nipples are inserted and another section placed in position fig. 3,810; the four short tie bolts are then tightened; in the last section is being put in position fig. ,811, and boiler erected is shown in fig. 3,812.

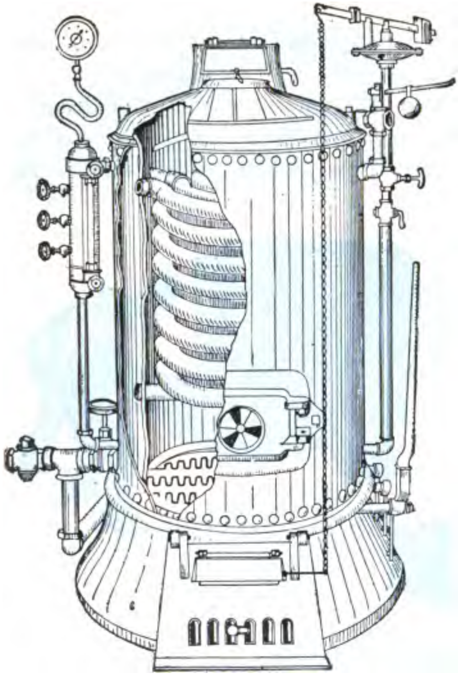
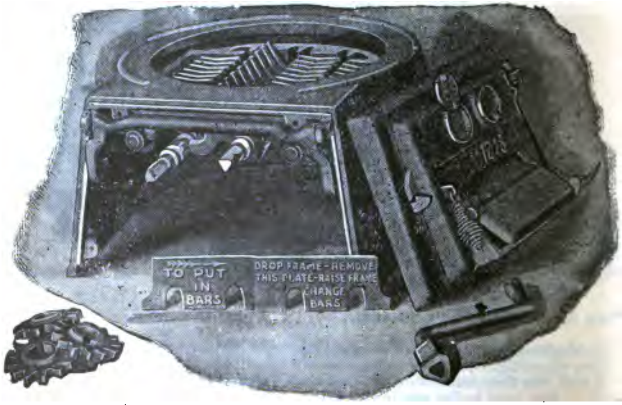


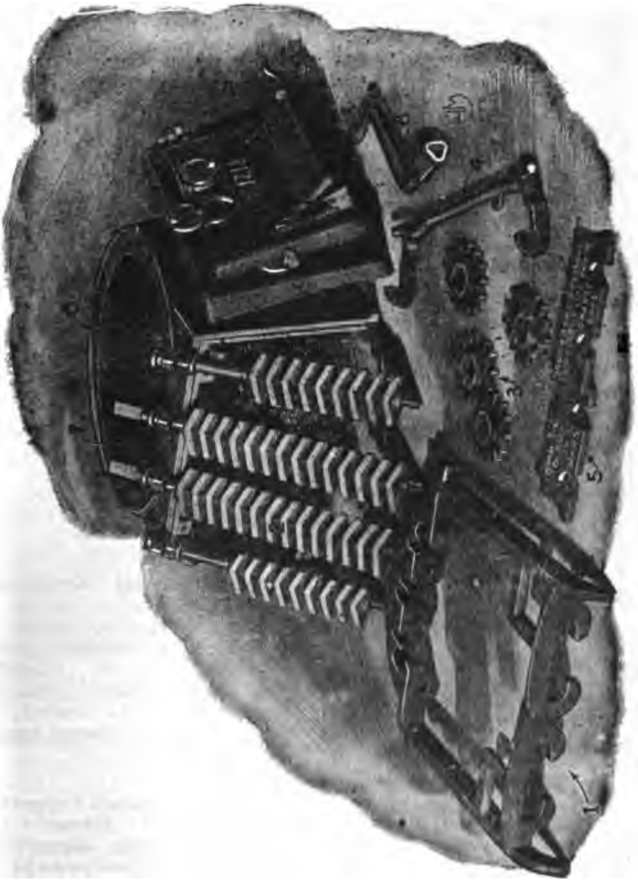
Fig. 3,813.—Monitor coil boiler. ***In type,*** this is a combined shell and water tube boiler. The cut shows plainly the general construction, thus requiring no description. The form of heating surface is very efficient.



Figs. 3,814 to 3,818.—International base, ash pit door, drop frame, grate gears and shaker.

Base.—This acts as a support for the fire pot and heating sections of the boiler. It should be so proportioned as to form a deep, commodious ash pit with a large ash door.

Usually a draught door is placed in the middle of the ash door, but in some designs, it is found on the side. This draught door should be balanced so accurately and work with such ease that it will open and close with the slightest variation of the steam pressure acting on the regulator.



FIGS. 3,819 to 3,832.—International base and grate dissembled. ***Directions for assembling the herringbone grate:*** Hang the drop frame 1, in the sockets 7; put the grate hanger 4, in the supports 9; now slip the grate bars 2, into the back holes 10, and front hooks 11. Slide the gears 3, onto the bars 2, and slip plate 5, into place.

The grate is located in the top of the base and is an important part of the apparatus. It should permit of both shaking and dumping, be easily accessible for repairs or renewal. Figs. 3,814 to 3,832 shows a typical base with ash and draught doors as constructed for a round, vertical boiler.

Fire Pot.—This is a most vital part of the boiler because, especially on account of the inadequate heating surface usually provided and the fact that the fire pot heating surface is more efficient than that further removed from the fire, the larger the fire pot heating surface and its coal capacity, together with proper combustion space and ample water passages, the more satisfactory will be the boiler's performance.

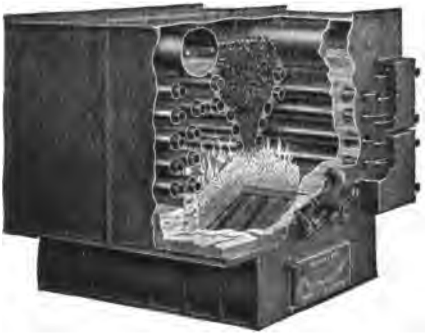


Fig. 3,833.—Spencer double tube magazine feed horizontal boiler showing general construction.

The fire pot in vertical boilers is usually made in a single casting, corrugations sometimes being provided to increase the heating surface.

In horizontal boilers it is built up from the sections, and also in some vertical boilers the fire pot is in several pieces. In the side openings are provided for the fuel and slice doors, the bottom of the slice door being on a level with the grate.

Intermediate Sections.—Superposed on top of the fire pot of vertical boilers are one or more *intermediate* sections (sometimes more), consisting of hollow castings containing the water to be heated, and whose exterior forms heating surface.

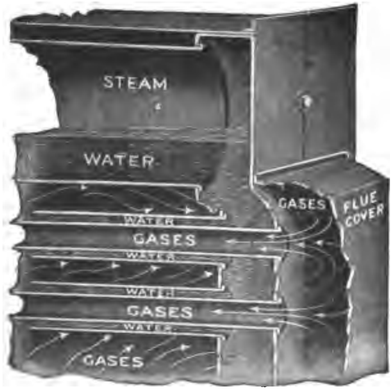
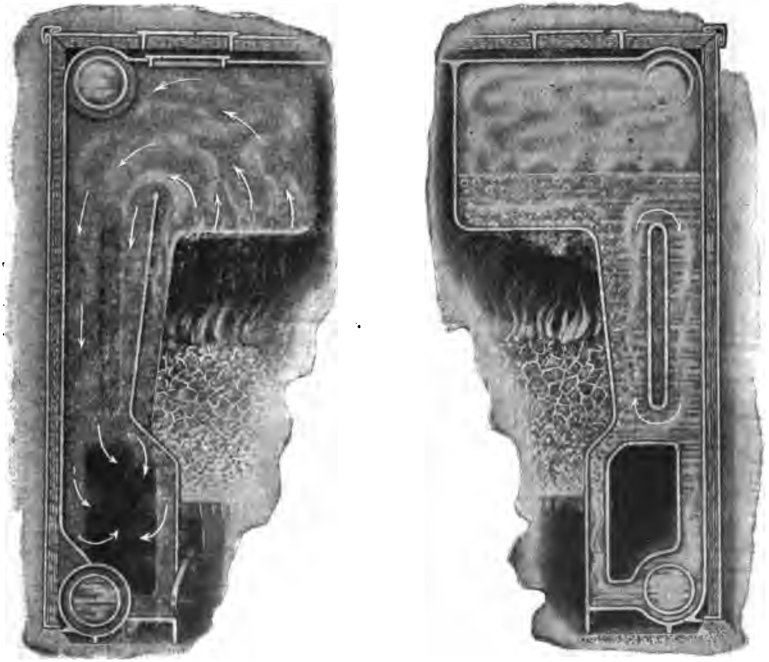


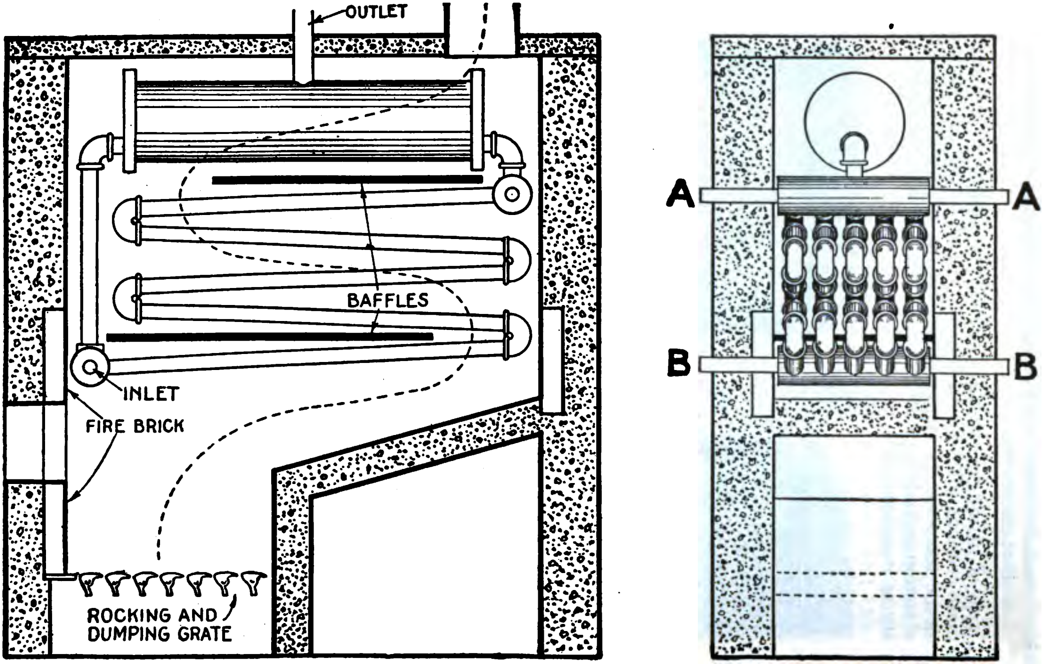
Fig. 3,834.—Gas and water travel in Spencer double tube boiler, showing water divided into annular streams between the outer and inner tubes with heating surface on both sides. This arrangement renders the heating surface very efficient.

Flue passages of proper area are provided through these castings, being staggered in adjacent sections so as to lead the gases in a roundabout way in traversing the heating surface, thus avoiding more or less short circuiting.

The practice of listing several sizes of boiler according to the number of intermediate sections piled up on the fire pot, all having the same size grate cannot be too strongly condemned; that is, by assuming different rates of combustion and adding a little extra heating surface, the rated radiation capacity is increased 50% or more. As a matter of fact, for house heating boilers there is in general a particular rate of combustion (depending upon the intervals between firing, available draught, kind of coal, etc.), that will give the best all round satisfaction. If this rate of combustion be say 4 pounds per square foot of grate per hour and the capacity of fire pot be proportioned for 8 hour intervals between firings, evidently a different rate of combustion would be required for increased radiation capacity, or else a larger grate.



FIGS. 3,835 and 3,836.—Half sections of Ideal horizontal heater showing flow of gases (fig. 3,835), and circulation (fig. 3,836).



Figs. 3,837 and 3,838.—Home made horizontal water tube boiler, designed by the author. Size of boiler grate, 2 square feet; heating surface, 50 square feet. It is made of ordinary pipe and pipe fittings. ***Material required:*** 125 feet of 1¼-inch pipe cut into 5-foot lengths making 25 5-foot lengths of pipe; 20 1¼-inch return bends; 2 branch tees, 5 1¼-inch run; 5½ feet of 6-inch pipe for drum; 2 6-inch by 2-inch reducing couplings for drum heads. A few extra feet of pipe for outlets, supports, down flow pipe, etc. Procure a grate, preferably of the shaking and dumping size and brick in as shown. The brick setting should be so constructed that by removing the top and unscrewing return connections AA and BB, the entire boiler can be lifted out in case of repairs.

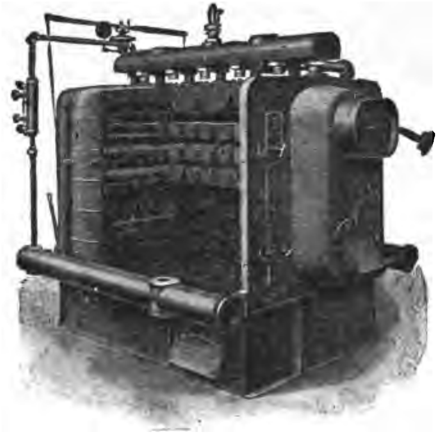


FIG. 3,839.—Gurney down draught boiler. ***Features:*** Separate half sections connected to top and side drums, cast iron sections in place of the usual one-piece castings, effective heating surface, accessibility for cleaning, steady water line, smoke consuming.

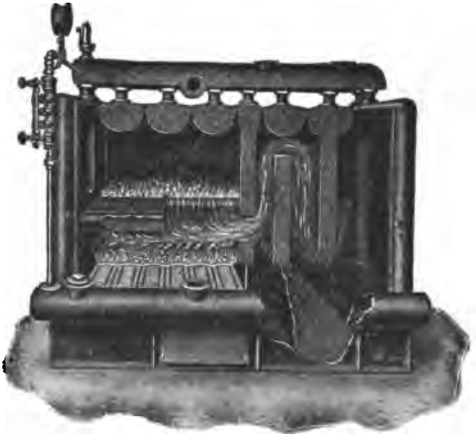


FIG. 3,840.—Gurney sectional boiler showing heating surface, long fire travel and horizontal arrangement of water tubes. Cut also shows method of dividing each section into half sections—a construction which insures freedom from breakage through sudden expansion or contraction.

Increased capacity with the same size grate, means, not only a higher rate of combustion, but in order not to decrease the 8-hour interval between firings, a larger quantity of coal must be put on at each firing and this means a deeper fire pot to hold the excess coal, and a higher available draught in order 1, to maintain the increased rate of combustion, and 2, to force the air through the greater depth of fuel.

In the selection of a heater these items should be considered, also that whereas cast iron heaters are more durable than wrought iron heaters, wrought iron is a better conductor of heat than cast iron, thus for equal efficiency more heating surface should be provided for cast iron than for wrought iron.

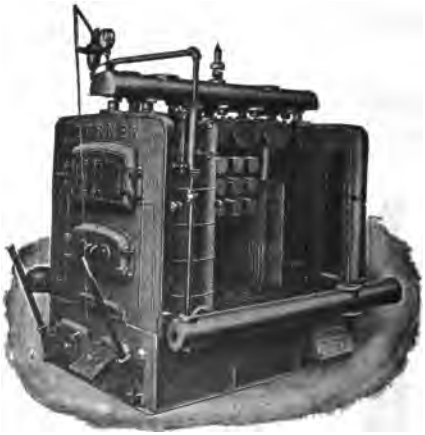


FIG. 3,841.—Gurney sectional boiler with bridge wall section and combustion chamber.

In the case of a vertical cast iron boiler, the author would recommend a high boiler consisting of several intermediate sections in preference to a low boiler without these sections, because the ratio of heating surface to grate area is increased. In support of this advice it is only necessary to quote the results obtained from tests (as given in one manufacturer's catalogue), several cast iron boilers all having the same size grate, but with different number of sections:

Steam Heating Boiler Tests

Number of boiler	Fuel anthracite pounds per square foot of grate	Area of grate square feet	Number of sections including dome	Steam produced per pound of coal	8 hour rating square feet
0	4.39	1.23	*1*	*7.5*	200
1	5.12	1.23	2	8.	250
1½	5.28	1.23	3	8.5	275
2	5.44	1.23	*4*	*9.*	300

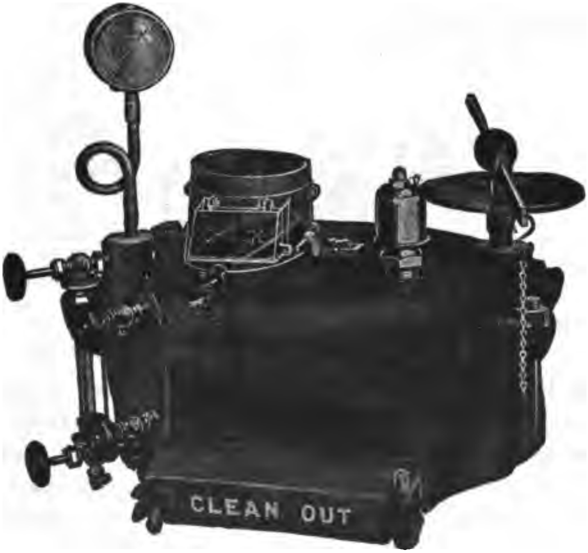


FIG. 3,842.—International steam dome showing water gauge, gauge cocks, steam gauge, damper, safety valve, automatic diaphragm regulator, and clean out door.

Since the number of sections as listed includes the top or dome, boiler O, had no intermediate sections. ***It will be noted*** that the evaporation in this boiler was only 7.5 pounds per pound of coal, and that even with the rate of combustion increased with the addition of intermediate sections, the evaporation increased from 7.5 to 9 pounds. It is simply a question of whether the purchaser prefers *a* ***cheap*** *boiler and* ***big*** *coal bill, or an* ***expensive*** *boiler and* ***small*** *coal bill*—that is for him to decide.

The ratio of heating surface to grate, according to Kent is given for low, medium and high boilers, as 15, 20 and 25 to 1, where the rate of combustion is respectively 4 and 5 pounds of coal per square foot of grate per hour.

The author believes that in no case should there be less than 25 square feet of heating surface per square foot of grate, in order:

1. To obtain high efficiency under normal operation.
2. To permit forcing in extreme cold weather without material loss of efficiency.
3. To obtain quicker response especially in starting the fire.

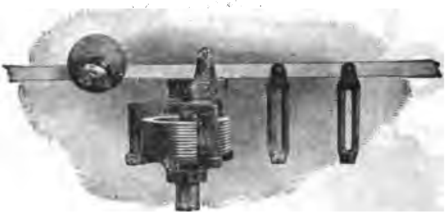


FIG. 3,843.—Ideal syphon steam regulator.

Steam Dome.—This section is placed on top of the intermediate sections in a vertical boiler and acts as a cover with an outlet to smoke stack and enclosed space for steam and water. In some designs the dome is really two sections cast in one piece that is two water spaces with a smoke space between.

The dome is usually made of larger diameter than the water section to increase the extent of the liberating surface and provide ample space for the steam so as to avoid priming.

Automatic Control.—In order that steam may be maintained at a constant pressure during the long intervals when the boiler is unattended, some method of automatic control of the

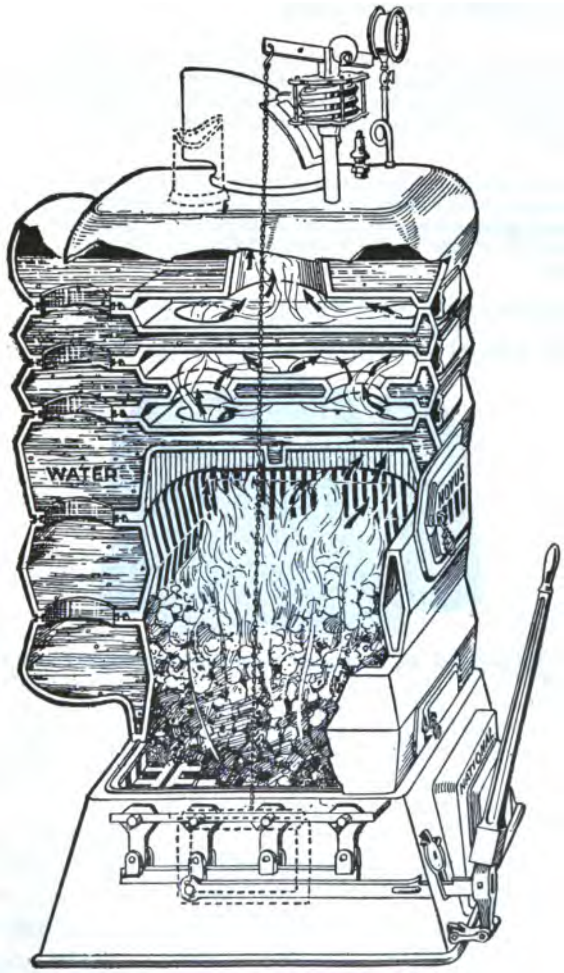


FIG. 3,844.—National boiler, sectional view showing interior construction and location of nipples.

fire is essential. This is accomplished by means of a diaphragm regulator as shown in figure 3,805.

In construction, two oval shaped castings form the case of the regulator, the upper one inverted and bolted to the lower one with a rubber diaphragm between. The lower casting is connected to the boiler (preferably below the water line), so that the steam pressure acts on the lower side of the diaphragm.

The upper casting has an opening in the center through which is placed a small plunger, whose lower end rests on the diaphragm and the upper end is bolted and pivoted to a long lever as shown. One end of the lever is connected by chains to the draught door and the other to a damper in the stack.

An adjustable weight is adjusted so that when there is no steam on the boiler it will push down the diaphragm and elevate the end connected to the draught door, which opens this door wide.

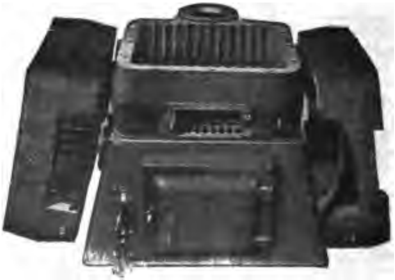


Fig. 3,845.—Three piece fire pot of National boiler showing corrugated walls to augment heating surface.

CHAPTER 68

DETAILS AND STRENGTH OF CONSTRUCTION

Construction Rules.—Manufacturers, engineers and steam users in general have devoted a vast amount of time and attention to the study of steam boilers. Much has been written and discussion upon the subject is frequently taking place among engineering societies, especially with reference to the *strength of parts*.

Formerly there has been a great lack of uniformity in the rules by different writers and by legislation.

In marine practice, boilers for merchant vessels must be constructed according to the rules and regulations prescribed by the Board of Supervising Inspectors of steam vessels; in the U. S. Navy, according to rules of the navy department, and in some cases according to special acts of Congress.

In some states such as Massachusetts and Ohio, and in some cities, for instance, Philadelphia, the construction must conform to local laws, but in many places there are no laws, the matter being left to the individual engineers and boiler makers.

Lately there has been a great effort toward standardizing construction, due to the activity of the American Boiler Manufacturers Association, American Society for Testing Materials, *and* **chiefly** to the work of the American Society of Mechanical Engineers, which in 1915 issued its *boiler code*, containing rules of construction and which is now the generally accepted standard, a digest of these rules being given in this chapter.

Boiler Plates.—This term was formerly used to denote superior qualities or brands of wrought iron rolled out into sheets, suitable for constructing shells or drums of steam boilers, but at present mild steel is the standard material.

A disadvantage of iron is that the plates were much shorter and narrower than can now be had in mild steel, because steel plates have no grain or fibre, but are of uniform character, and can accordingly be rolled lengthwise or crosswise as may be most conveniently done in the rolling mill. The advantage of this is a reduction of the number of plates and riveted joints comprising a shell.

The *A.S.M.E. Code* requirements for boiler plate are given in the chapter on boiler materials:

***Marine Rules**—Boiler Plate.*

Rule I, 1.—Every iron or steel plate intended for the construction or repairs of boilers to be used on steam vessels shall be stamped by the manufacturer in the following manner:

At two diagonal corners, at a distance of about 8 inches from the edges, and at or near the center of the plate, with the name of the manufacturer, place where manufactured, and the number of pounds tensile stress it will bear to the sectional square inch, expressed in thousands.

Every iron or steel plate to be used in the construction or repairs of boilers for steamers navigated under the provisions of Title LII, Revised Statutes, which will be subject to tensile strain in said boilers shall be tested and inspected by an inspector duly authorized under the provisions of said title, and such plates shall not be stamped until they have been tested by the inspector, and each of such plates shall then be stamped by the manufacturer in the presence of the inspector with the minimum number of thousand pounds tensile stress it will bear to the sectional square inch.

All plates which conform to the physical, chemical, and other requirements prescribed by these rules shall be stamped by the inspector near the manufacturer's stamp, with the official stamp of the United States Steamboat-Inspection Service, and with the initials of his name and a serial number. (Sec. 4430, R. S.)

Rule I, 2.—Plates may be tested and inspected at the mills for repairs to marine boilers or to be carried in stock, the report of such test to be in duplicate, one copy to be furnished through the supervising inspector to the local inspectors in the district where the purchaser of such material is located, and the other to the purchaser, who shall deliver a copy of the same to the parties using the material, who, in turn, shall submit the same to the local inspectors in the district where the material is to be used, before being assembled in the boiler. Steamers carrying such repair material to be used in emergencies shall carry the record of each sheet of such material on board. (Secs. 4430, 4431, R. S.)

Rule I, 3.—Boilers built since February 28, 1872, of material stamped and tested according to the requirements of section 4430, Revised Statutes, and having a record thereof in the office of the local inspectors in the district where the boiler was built or intended to be used, may be used for marine purposes, notwithstanding that such boilers may have been used for other purposes, if in the judgment of the local inspectors they are deemed safe. (Sec. 4430, R. S.)

Rule I, 4.—Steel plates shall be made by the open-hearth process, except that steel for plates to be used in the manufacture of boiler tubes may be made by the Bessemer process.

Open-hearth steel shall contain not more than .04 per cent of phosphorus nor more than .04 per cent of sulphur.

The manufacturer shall furnish the inspector, with each order tested, a certificate stating the process by which the steel was manufactured and a copy of the analysis of each melt.

The Shell.—Although the heat transmitting power of steel plate even of considerable thickness, when perfectly clean is beyond anything demanded in boiler practice, it is a fact that a very thin film of grease, or a coating of scale of many varieties in composition covering a plate so retards the rate of flow of heat through the plate as to cause its temperature to rise to the point at which its tensile strength has become greatly lowered. This results in burning or serious distortion from form, often producing blisters, bulging and sometimes complete failure.

***Marine Rules.**—Boiler Plate.—Continued*

The analysis may, if deemed expedient by the Supervising Inspector General, be verified at the expense of the manufacturer. (Secs. 4405, 4430, R. S.)

RULE I, 5.—When the tensile strength determined by the test is less than 63,000 pounds, the minimum elongation shall be 25 per cent for plates three-fourths inch and under in thickness and 22 per cent for plates over three-fourths inch in thickness. The quench bend specimen shall bend through 180° around a curve the radius of which is three-fourths the thickness of the specimen. When the tensile strength determined by the test is 63,000 pounds or greater the minimum elongation shall be 22 per cent for plates three-fourths inch and under in thickness, and 20 per cent for plates over three-fourths inch in thickness. The quench bend specimen shall bend through 180° around a curve the radius of which is one and one-half times the thickness of the specimen. (Sec. 4430, R. S.)

RULE I, 6.—The tensile strength shall be not less than 45,000 pounds per square inch. The elongation shall be not less than 15 per cent. The reduction of area shall be not less than 15 per cent for 45,000 pounds tensile strength, and for each increase of 1,000 pounds tensile strength up to 55,000 pounds, an addition of 1 shall be made to the required percentage of reduction of area. The bend test specimen shall bend cold through 90° around a curve, the radius of which is not greater than one and one-half times the thickness of the specimen. (Sec. 4430, R. S.)

RULE I, 7.—Tension test specimens shall be milled with the following dimensions: Length at least 16 inches, ends from 1½ to 3½ inches wide by about 3 inches in length, and parallel section at center 1 to 1½ inches wide by 9 inches in length. The percentage of elongation shall be measured in a gauge length of 8 inches.

Where specimens are to be tested on the testing machines of the Steamboat-Inspection Service, they shall be 1 inch wide at parallel section in center, and shall not exceed 2 inches in width on the ends.

Bend test specimens shall be at least 12 inches in length and from 1 to 3½ inches in width, and the full thickness as rolled. The edges may be planed. The corners shall not be rounded, but the sharpness may be removed with a fine file. After bending, the specimens shall show no cracks or flaws on the outside of the bent portion.

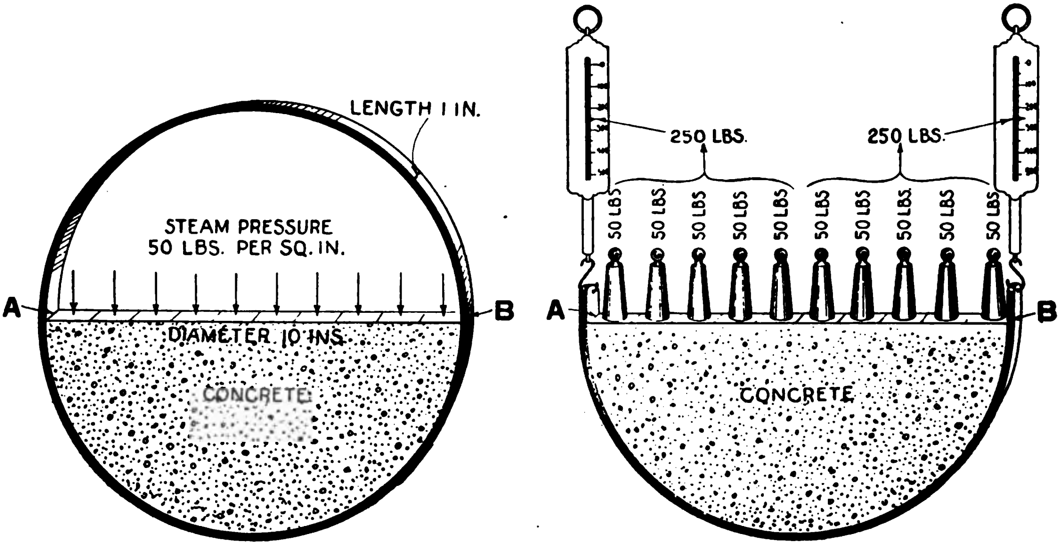
Bend test specimens for steel plates, before bending, shall be heated to a cherry red as seen in the dark, and quenched in water the temperature of which is about 82° F.

Two tension and two quench bend tests shall be made from each plate as first rolled from the billet, slab, or ingot.

The tension test specimens shall be cut from diagonal corners and the bend test specimens shall be cut from the other diagonal corners.

The finished material shall be free from all injurious defects, and shall have a good and workmanlike finish.

All measurements of test specimens and material shall be made by any standard American gauge, and record of tests shall be submitted on Form 934. (Secs. 4405, 4430, R. S.)



FIGS. 3,846 and 3,847.—Section of boiler shell, illustrating ***total pressure*** to which the metal of the shell is subjected.

The experience of engineers in early years on the Mississippi river and its tributaries shows that it is not safe with those muddy waters to have the metal in the shell of the steam boilers more than $^3/_{10}$ inch in thickness. Anything thicker is sure to burn out on the laps. In addition to this, it has been well proven in practice that anything, no matter what, that prevents water actually touching the metal ***where a high temperature gas is on the other side of the metal***, will produce over-heating in the metal and consequent failure by burning or distortion from the original form.

Since nearly all waters available for boiler purposes carry impurities varying widely in amount and kind, it is apparent that the thickness of the plate which can be used in practice in the shell of these boilers is narrowly limited. For boilers with shells exposed to the fire, experience has set ½ inch in thickness as a maximum where good water is available, but for general practice $^7/_{16}$ inch in thickness is undoubtedly safer and better.

Having adopted this limit of thickness in the shell of such boilers, calculation at once shows that either the diameter of the boiler must be small, if moderately high pressures be desired, or in the presence of large diameters, that low pressures must be carried. It further becomes evident that, being limited in diameter for a desired pressure, the size of the unit must also be limited.

Courses.—The quality of the metal having been selected, the number of *courses* or sections which is to make up the shell and the manner of riveting these courses together must have thorough consideration.

Experience has demonstrated that it is always better to use one plate or *sheet* for each circumferential course, thus enabling the bringing of the longitudinal joint well up above the fire line in place of using one plate under the entire length of the boiler, which necessitates, owing to its limit in size, bringing the longitudinal joints down into the gas passage.

In earlier times, the number of courses of which a boiler was made, as previously mentioned, was limited by the power of the mills to produce large plates. As the mills have grown, larger and larger plates have been made and used. Experience enough has now been gained with large plates to show that to preserve stiffness, courses should not exceed nine feet in length and some designers prefer that a foot shorter be the limit.

Strength of the Shell.—To determine the strength of the shell it is necessary to consider:

1. Steam pressure.
2. Diameter of shell.
3. Thickness of shell.
4. Efficiency of the joint.

In making the calculation, a section of the shell *one inch long* is taken and its diameter is expressed in inches because the steam pressure, as indicated by the steam gauge, means the pressure acting on each square inch. The thickness of the shell is expressed as a fraction of an inch.

Now consider a one-inch section of a shell 10 inches in diameter and suppose the lower half to be filled with concrete and the upper half subjected to a steam pressure of 50 pounds per square inch, as in fig. 3,846.

Since the shell is 10 inches in diameter and one inch long, evidently the area of the concrete surface exposed to the steam pressure is $10\times1=10$ square inches, and as there is 50 pounds steam pressure acting on each square inch, the **total pressure** on the concrete is

$$50\times10=500 \text{ pounds}$$

This total pressure is plainly carried by the metal of the shell at A, and B, hence half of it is carried by A, and half by B.

For clearness, imagine half of the shell to be cut away and the lower half supported by two spring scales as in fig. 3,847. Now, substituting for the steam pressure 50-pound weights, one placed on each square inch of the concrete, evidently each scale will indicate a pull of 250 pounds, that is, the metal of the shell at A, is subjected to a force of 250 pounds tending to pull it apart, the same conditions existing at B, also. This force must be expressed in ***pounds per square inch*** because the tensile strength of the metal is taken in pounds per square inch.

Now if the shell were one inch thick there would be one square inch area of metal in section A, of the shell, hence the stress in the shell would be 250 pounds per square inch.

If, however, the shell be, say, only ⅛ inch thick, the area of section A, would be $\frac{1}{8} \times 1 = \frac{1}{8}$ square inch, and the total pressure of 250 pounds would be carried by only ⅛ square inch of metal, hence the stress would be increased 8 times, that is, the metal would be subjected to a stress of

$$250 \div \tfrac{1}{8} = 250 \times 8 = 2{,}000 \text{ pounds per square inch}$$

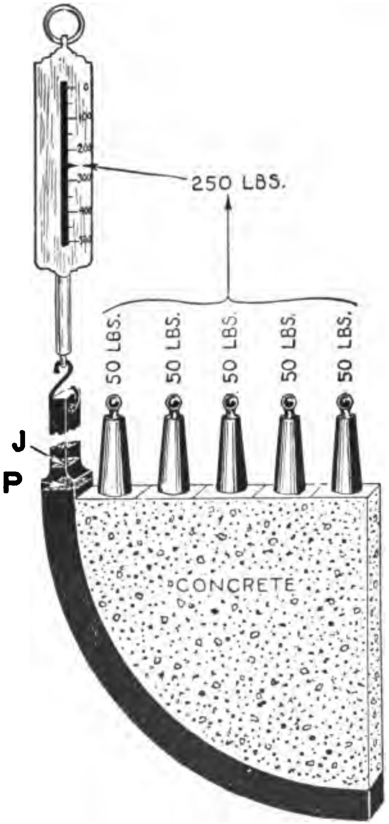


Fig. 3,848.—Half section of shell, illustrating *efficiency of the joint.*

Ques. What important point remains to be considered?

Ans. The riveted joint.

Ques. Why?

Ans. Because the strength of the joint is *always* ***less*** than the strength of the plate.

Ques. What is the ratio of the strength of the joint to the strength of the plate?

Ans. The *efficiency* of the joint.

Evidently, from figs. 3,846 and 3,847, it is only necessary to consider half of the shell to determine its strength, as shown in fig. 3,848.

In boiler construction the ends of the plates are joined together usually by riveting instead of welding. This seam or *joint* is *necessarily weaker* than the solid plate because part of the metal of the plate is cut away for holes for the rivets, hence the importance of considering this part of the shell.

From figs 3,846 and 3,847 it is evident that only a half longitudinal section of the shell need be considered in calculating the strength. Let fig. 3,848 represent such section, and imagine that the thickness of the plate end be reduced so that section **J**, will represent the strength of the joint as compared with full section **P**, which represents the strength of the solid plate. The *efficiency* of the joint then will equal *area* **J** ÷ *area* **P**. That is if the thickness of the plate be ¼ inch at **P**, and ⅛ inch at **J**, the respective areas are .25 and .125 square inches, and the efficiency of the joint is .125 ÷ 25 = .5, or 50 per cent.

Example.—If the efficiency of the joint in fig. 3,848 be 50 per cent, and the plate be ¼ inch thick at section **P**, what is the stress on the metal at the joint?

The total pressure coming on the full plate section is 250 pounds and since the plate is ¼ inch thick, the stress on section **P**, is

250 ÷ ¼ square inch = 1,000 pounds

The efficiency of the joint being 50 per cent, the area of section **J**, will be one half of **P**, or ½ of ¼ = ⅛ square inch, hence

stress along the joint = 250 ÷ ⅛ = 2,000 pounds

The same result is obtained by dividing the stress on the solid plate by the efficiency of the joint, that is, 1,000 ÷ .5 = 2,000 pounds.

From the foregoing explanations the following rules must be self evident.

1. To find the total pressure to be carried by the shell

RULE.—*Multiply the gauge steam pressure in pounds per square inch by the radius of the shell expressed in inches.*

2. To find the stress coming on the shell

> ***Rule.****—Divide the total pressure* (*as found in* 1) *by the area of the solid plate per inch length of longitudinal section, and by the efficiency of the joint.*

Expressed as a formula

$$\textit{stress in shell} = \frac{\textit{steam pressure} \times \textit{radius of shell}}{\textit{thickness of solid plate}^{*} \times \textit{efficiency of joint}}$$

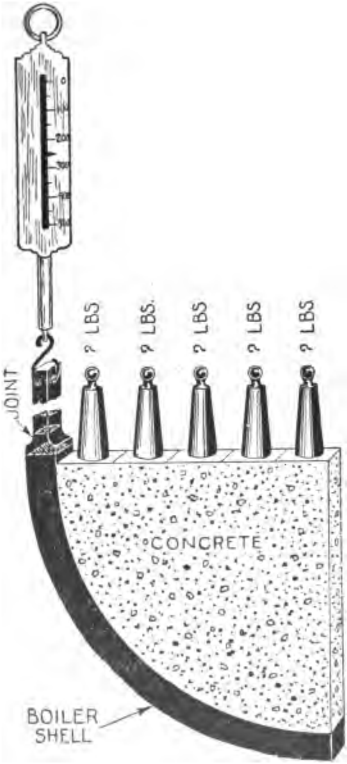


FIG. 3,849.—Half section of shell, illustrating ***bursting pressure.*** The concrete indicates uniform distribution of pressure due to the weights.

Bursting Pressure.—The determination of the bursting pressure is a very important calculation, for upon this depends the maximum pressure to be allowed in operation. The bursting pressure depends upon:

1. Tensile strength of the shell.
2. Thickness of the shell.
3. Radius of the shell.
4. Efficiency of the joint.

Considering a half section as in fig. 3,849, evidently if the internal pressure acting on the shell indicated by the weights be sufficient to bring a stress in the metal equal to its tensile strength, the shell will be pulled apart or ruptured as shown, the rupture taking place at the weakest section of the joint.

Now if the thickness of the solid plate be ¼ inch and the efficiency of the joint be 50 per cent, then the equivalent thickness of solid metal where strength is equal to that of the joint is 50 per cent of ¼ = ⅛ inch.

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*NOTE.—Since one inch length of shell is being considered, the thickness of plate and area of longitudinal sections are numerically the same

If the tensile strength of the metal be 60,000 pounds per square inch, ⅛ of this would be the corresponding force necessary to rupture joint, or

⅛ of 60,000 = 7,500 pounds

That is, the total pressure necessary to burst the boiler is 7,500 pounds, acting on the half section, and since this pressure is distributed over an area of 5 square inches, the equivalent steam pressure *per square inch* is

7,500 ÷ 5 = 1,500 pounds

Accordingly, the following rule

1. **To determine the bursting pressure**

RULE.—*Multiply the thickness of the shell (expressed in inches or fraction of an inch), by the efficiency of the joint and by the tensile strength of the metal. Divide the product by the radius of the shell and the result will be the bursting pressure in pounds per square inch.*

Factor of Safety.—Because of the disastrous consequences which attend boiler explosions it is necessary that boilers be of sufficient strength to withstand several times the maximum pressure of operation or *working pressure**.

The ratio of the bursting pressure to the working pressure is called the factor of safety, that is

factor of safety = bursting pressure ÷ working pressure

The Working Pressure.—The maximum pressure to be allowed at which it is considered safe to operate a boiler depends on:

1. Tensile strength.

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*NOTE.—The *working pressure* is the *maximum pressure* safe to carry on a boiler consistent with the factor of safety employed in the design; it should not be confused with the *running pressure*, that is, with the pressure ordinarily carried in running the engine. The safety valve is usually set to blow off at the *working pressure*, hence, the *running pressure* of necessity must be lower. If the working pressure of a boiler be 100 pounds and the bursting pressure be 600 pounds, then the factor of safety is, 600 ÷ 100 = 6.

2. Thickness of the shell.
3. Radius of shell.
4. Efficiency of the joint.
5. Factor of safety.

Example.—What is the maximum allowable working pressure to be carried on a boiler 50 inches in diameter, tensile strength 60,000 pounds, plates ⅜ inch thick, efficiency of joint 87 per cent, factor of safety 5.

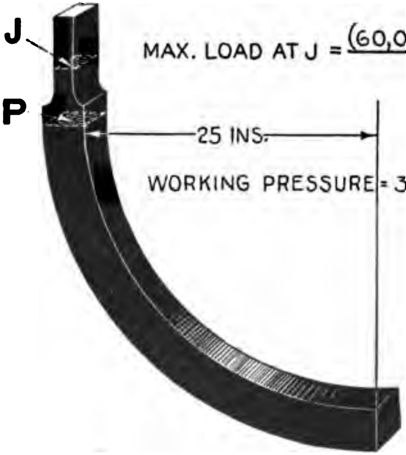

J
P
MAX. LOAD AT J = (60,000 X ⅜) X 87% / 5 = 3,915 LBS.
25 INS.
WORKING PRESSURE = 3,915 ÷ 25 = 156.6 LBS.

FIG. 3,850.—Half section of shell, illustrating method of determining the ***working pressure***.

A tensile strength of 60,000 pounds corresponds to a stress of

60,000×⅜ = 22,500 pounds

in a ⅜-inch plate per inch length of section, and for a factor of safety of 5 the maximum load allowable on the solid metal of the shell is

22,500÷5 = 4,500 pounds

Considering the efficiency of 87 per cent of the joint, this load must be reduced to

87 per cent of 4,500 = 3,915 pounds

not pounds per square inch, but the **maximum** *allowable force* tending to pull the metal of the shell apart. Since this force is distributed over the radius of the shell or 50 ÷ 2 = 25 inches (that is, 25 square inches, considering 1 inch length of shell), the maximum allowable working pressure is

$$3{,}915 \div 25 = 156\tfrac{1}{2} \text{ pounds}$$

Expressed as a formula the problem becomes

$$\text{working pressure} = \frac{\text{tensile strength} \times \text{thickness of plate} \times \text{efficiency of joint}}{\text{radius of shell} \times \text{factor of safety}}$$

or using the usual symbols

$$\textbf{Working Pressure} = \frac{T \times t \times E}{R \times F}$$

in which

T = ultimate tensile strength stamped on shell plates, pounds per square inch.

t = minimum thickness of shell plates in weakest course, inches.

E = efficiency of longitudinal joint or of ligaments between tube holes (whichever is the least).

R = inside radius of the weakest course of the shell or drum, inches.

F = factor of safety, or the ratio of the ultimate strength of the material to the allowable stress.

Thickness of the Shell.—After figuring the size of a boiler for a given capacity, about the first problem that confronts the designer is to determine the proper thickness necessary for safety. This depends on:

1. Working steam pressure.
2. Radius of the shell.
3. Efficiency of the joint.
4. Tensile strength of the plate.
5. Factor of safety.

The following example will serve to illustrate the method of solving the problem.

Example.—What thickness of shell is required for a 50-inch boiler suitable for 125 pounds working pressure, if the tensile strength of the plates be 60,000 pounds, efficiency of joint 82 per cent, factor of safety 5.

The total pressure to be carried by the shell is equal to

$$\text{radius} \times \text{working pressure} = 25 \times 125 = 3{,}125 \text{ pounds}$$

Since the factor is 5, the shell must be strong enough to withstand 5 times this load or

$$5 \times 3{,}125 = 15{,}625 \text{ pounds}$$

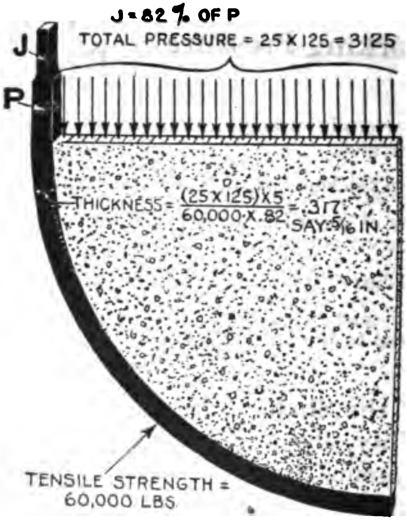

J = 82 % OF P
TOTAL PRESSURE = 25 X 125 = 3125
J
P
THICKNESS = (25 X 125) X 5 / 60,000 X .82 = .317 SAY 5/16 IN.
TENSILE STRENGTH = 60,000 LBS.

Fig. 3,851.—Half section of shell, illustrating method of determining ***thickness of shell.***

If the efficiency of the joint were 100 per cent, and with 60,000 pounds tensile strength, the thickness of shell would be

$$15{,}625 \div 60{,}000 = .26 \text{ inch}$$

Now, since the efficiency of the joint is only 82 per cent, the thickness of the shell is

$$.26 \div .82 = .317 \text{ or say } \tfrac{5}{16} \text{ inches}$$

According to the *A. S. M. E. Code*, the minimum thickness of boiler shell plates, and dome plates after flanging, shall be as follows:

Minimum Thickness for Boiler Plate (A.S.M.E. Boiler Code)

Diameter of Boiler	36 inches or under	36 to 54 inches	54 to 72 inches	Over 72 72 inches
Minimum thickness of plates.	¼ inch	$\frac{5}{16}$ inch	⅜ inch	½ inch

Thus the calculated thickness comes within the limit of the table.

Riveted Joints.—The ends of the plate or plates forming a *course* or band section of the shell are joined together by rivets, and since part of the metal must be cut out of the plate to provide holes for the rivets, the strength of the joint is *always* ***less*** than that of the solid plate, though by the use of the more complicated forms of riveted joint, the strength of the latter can be made almost equal to that of the *solid* plate.

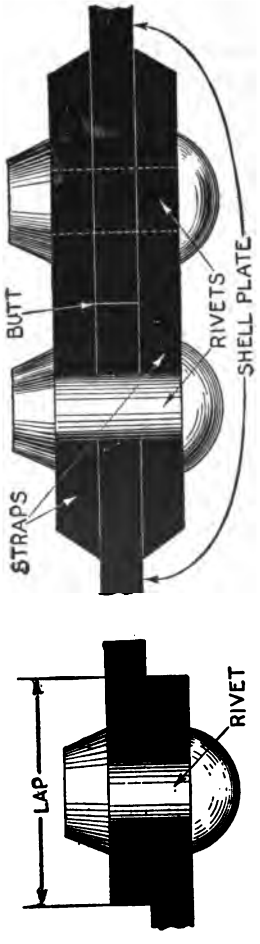
The various forms of riveted joint have become well standardized during the advance in the art of boiler making, and these various forms may be classified as:

1. Lap joints
    - single riveted
    - double riveted
    - with cover plate
2. Butt and double strap
    - double riveted
    - triple riveted
    - quadruple riveted
    - quintuple riveted

Ques. What is the difference between a lap and a butt joint?

Ans. The plate ends overlap to form a lap joint and register with each other to form a butt joint as shown respectively in figs. 3,852 and 3,853.

NOTE.—The likelihood of failure by shearing of rivets and by tearing of the plate will be equalized when the shearing strength of the rivets is equal to the tearing strength of the plate between rivet holes. In the case of a lap joint the rivet will shear at only one section.



FIGS. 3,852 and 3,853.—Single riveted lap joint and single riveted butt and double strap joint.

Ques. What is the objection to a lap joint?

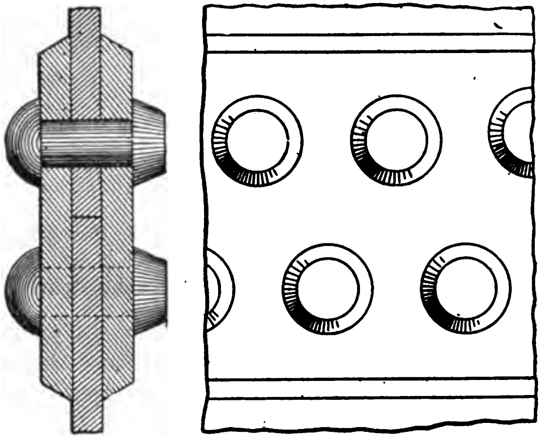
Ans. The plate end, through which the rivets passs being in different planes, the pull is not direct, but tends to twist the plates, frequently causing them to bend as shown in fig. 3,859, and sometimes resulting in an explosion.

The Hartford Steam Boiler Insurance Co. criticise the lap joint as follows:

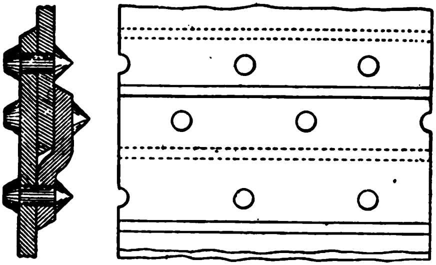
"The fearful boiler explosion at Brockton, Mass., was due to an undiscoverable defect known as a 'lap joint crack'. Although there is nothing new about this defect, which has been known and recognized for many years among boiler experts, yet the terrible Brockton disaster has attracted greater attention to it, and the general interest that is felt is well shown by the many letters that we have received and also by the numerous articles that have appeared in periodicals, both technical and general."

For the girth or circumferential seam which runs around the boiler there is no great objection to the lap joint, but for a longitudinal seam where the disposition of the metal is not such as to resist so effectively the twisting action, only the butt and double strap joint should be used on boilers for moderate or high pressures.

Ques. In designing a riveted joint what is the chief object in view?

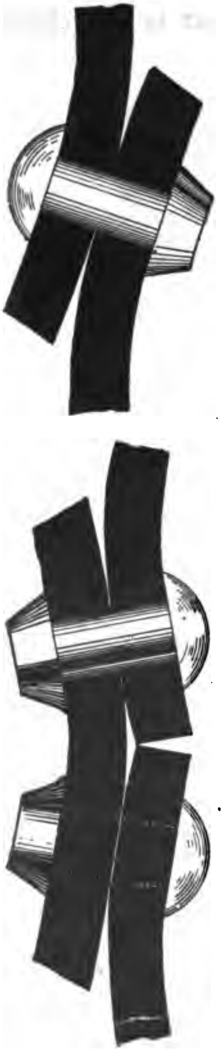


Figs. 3,854 and 3855.—Butt joint with two covers.



Figs. 3,856 and 3,857.—Lap joint with cover plate or offset strap. It is safer than the plain lap joint but not as good as the butt joint with double strap.

Ans. To so proportion it that it will be equally strong against failure by all possible ways of breaking.



Figs. 3,858 and 3,859.—Effect of pull on lap joints and butt joints with one cover.

These are: 1, shearing of the rivets, 2, tearing apart of the plate along the last row of rivet holes, 3, crushing down of the metal in front of the rivets, or the rivet itself, 4, shearing of the metal between a rivet and the edge of the plate (this is possible only in case of single riveted joint), 6, a combination of any of these items just mentioned.

Ques. What is the distance between centers of adjacent rivets in the same row called?

Ans. The *pitch*, as shown in fig. 3,860.

Ques. What is diagonal pitch?

Ans. It is, where there are two or more rows of rivets, the distance between the centers of diagonally adjacent rivets, as shown in fig. 3,860.

Ques. What is back pitch?

Ans. The distance between the center lines of any two adjacent rows of rivets measured at right angles to the direction of the joint as shown in fig. 3,860.

Ques. What is the difference between single and double shear?

Ans. Single shear occurs in one plane as in a lap joint, and double shear in two planes as in a butt and double strap joint.

Ques. What is the advantage of double shear?

Ans. The force necessary to shear a rivet in one plane as in single shear is equal to the cross-sectional area of the rivet multiplied by its shearing strength, hence if it shear in two planes as in double shear, the force necessary to shear the rivet is doubled.

In practice it is taken at 1¾ to allow for imperfection of construction whereby more force may be exerted on the rivet by one strap than by the other.

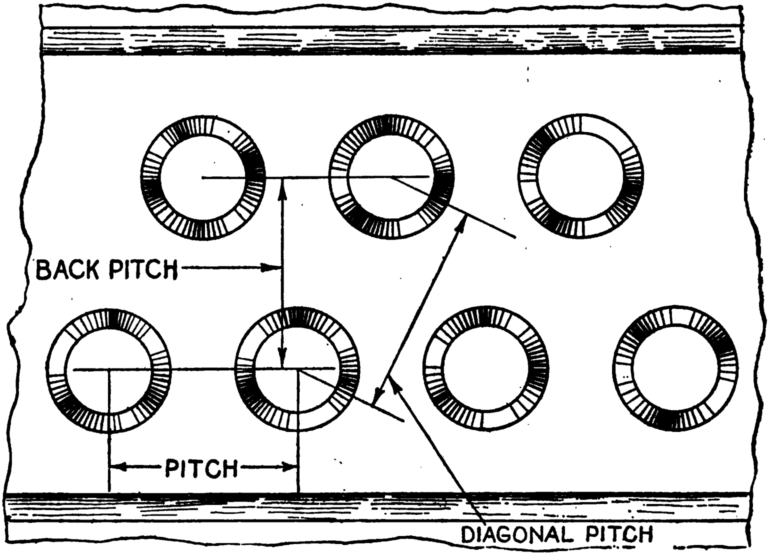
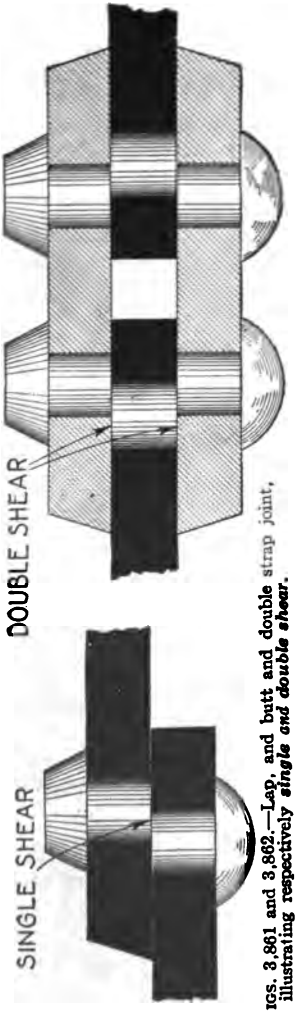


FIG. 3,860.—Double riveted butt joint, illustrating ***pitch, diagonal pitch*** and ***back pitch.***

Ques. What is the efficiency of a riveted joint?

Ans. The *ratio* which the strength of a unit length of a riveted joint has to the same unit length of the solid plate.

NOTE.—***The efficiency increases*** as the rivet diameter and pitch is increased; there is, however, a practical limit to the increase of the diameter due to the difficulty of heading up very large rivets, and a limit to the increase of the pitch due to the necessity of guarding against eakage.



FIGS. 3,861 and 3,862.—Lap, and butt and double strap joint, illustrating respectively *single and double shear.*

Ques. How is the strength of a riveted joint determined?

Ans. It depends on whether the plate or the rivets be the stronger of the two.

Theoretically in a properly designed joint, the strength of the plate and that of the rivets should be equal so that there will be no more chance of failure in one way than the other. However, in practice since corrosion usually affects the plate only, it is often considered good practice to make the plate slightly stronger, so that even after some wasting by corrosion the joint may still be in fair proportion as to the relative strength of plate and rivets.

How to Calculate a Riveted Joint.—In determining the strength of any form of riveted joint a unit length or *element* of the joint is taken, the length considered depending upon the arrangement of the rivets and is equal to the greatest pitch.

Evidently no further section need be considered because the entire seam is composed of similar elements having the same symmetrical arrangement of rivets and plate metal.

In calculating any riveted joint there are these three things to be determined:

NOTE.—"The investigation of the strength of riveted joints by any simple theory is necessarily quite imperfect, because we do not know in just what way the stress is distributed through the remaining part of the plate, nor through the section of the rivet, nor what allowance to make for the frictional grip of the joint" —*Durand.*

1. Strength of the plate.
2. Strength of the rivet or rivets.
3. Efficiency of the joint.

The method of calculating the various riveted joints will now be given.

Single Lap Joint.—This is the simplest and most inefficient joint, and is made by lapping the plate ends a proper distance and securing with a single row of rivets.

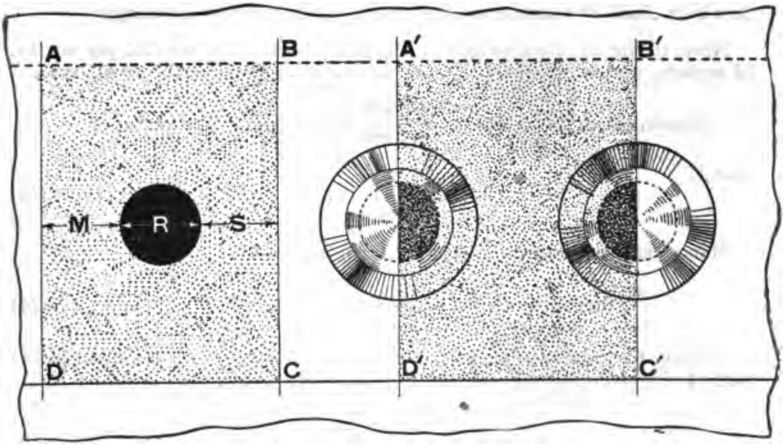


FIG. 3,863.—Single riveted lap joint, illustrating ***element*** of the seam to be considered in determining the strength of the joint. The shaded portion ABCD is the element; its equvailent A′B′C′D′ may also be considered as an element .

In fig. 3,863, ABCD, is the *element* of the joint to be considered. Evidently, since R, has been cut out of the plate for the rivet, the solid metal of the plate left to resist the pull is M+S, or since M+R+S is equal to the pitch.

Strength of plate = thickness × (pitch—diam. of rivet) × tensile strength;

or, as expressed with the usual symbols

Strength of plate $= t\ (P - d)\ T$ ....(1)

in which t = thickness of plate; P = pitch; d = diameter of rivet, and T = tensile strength.

Similarly

strength of rivet = section area of rivet × shearing strength

or expressed as a formula:

$$\text{strength of rivet} = .7854\, d^2 \times S \ldots\ldots (2)$$

in which .7854 d^2 = section area of rivet, and S = shearing strength.

Now, if the tensile strength of the plate be say 60,000 lbs. per sq. in. of section, and say, 40,000 lbs. per sq. in. of section for the rivet, then

$$\text{Shearing strength of rivet} = \frac{40,000}{60,000} \text{ tensile strength of plate, or}$$

that is

$$S = \frac{2}{3} T \ldots\ldots (3)$$

Hence, substituting this value for S, in equation (2)

$$\text{Strength of rivet} = .7854\, d^2 \times \frac{2}{3} T = .524\, d^2\, T \ldots\ldots (4)$$

Now, for equal strength of plate and rivet the values obtained in (1) and (4) for strength of plate and rivet must be equal, that is

$$t\,(P-d)\,T = .524\, d^2\, T$$

or (5)

$$t\,(P-d) = .524\, d^2$$

The strength of the solid plate must be considered to determine the efficiency of the joint. Evidently

Strength of **solid** *plate = thickness × pitch × tensile strength* = t PT (6)

Now, since efficiency of the joint = strength of joint ÷ strength of *solid* plate, and since strength of plate at the joint = strength of the rivet, then form equations (1), (4) and (6).

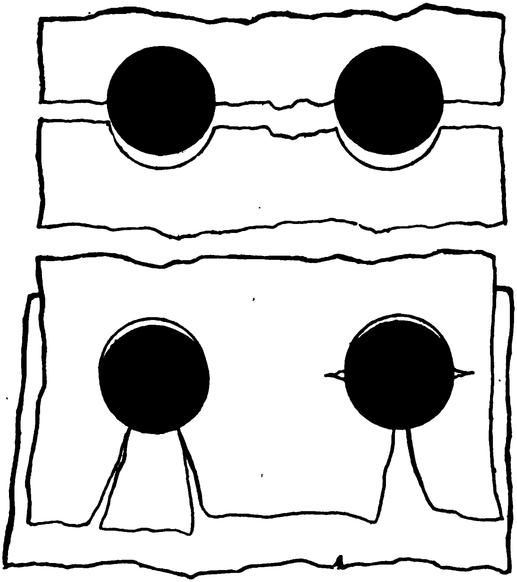
$$\text{Efficiency} = \frac{t\,(P-d)\,T}{t\,PT} = \frac{.524\, d^2\, T}{t\,PT}$$

or reduced to lowest terms

$$\text{Efficiency} = \frac{P-d}{P} = \frac{.524\, d^2}{t\,P} \qquad (7)$$

One item not considered in the calculations just given is the strength of the plate against shearing between rivet and edge of plate as shown in fig. 3,865.

This is guarded against by placing the rivet hole at a proper distance from the edge of the plate, which by experience, is found to be about one diameter solid metal, that is, 1½ diameters from edge of plate to center of rivet hole.



FIGS. 3,864 and 3,865.—Failures of riveted joints; fig. 3,864, fracture between rivets; fig. 3,865 split and double sheer between rivets and edge of plate. The first is caused by the rivets being too close together, that is, not enough metal in the plate between rivet holes, and the second is due to insufficient metal between rivet holes and edge of the plate.

In practice, the diameter of the rivet is taken at from 1.5 to 2.5 times the thickness of the plate, the lower values being more commonly employed with very thick plates on account of the difficulty of heading up excessively large rivets, and the necessity of a moderate pitch to allow proper calking to prevent leakage. In order, furthermore, to guard against danger of rupture by crushing the upper limit, 2.5, should not be exceeded.

The foregoing calculations are intended to illustrate the principles involved, and if thoroughly understood there should be nc difficulty in applying them to the more complicated joints.

The American Society of Mechanical Engineers has made an exhaustive study of the subject and in its boiler code have formulated rules for calculating the various forms of joint, which will now be given.

RIVETED JOINTS

According to

A.S.M.E. Boiler Code

Efficiency of Riveted Joints.—The ratio which the strength of a unit length of a riveted joint has to the same unit length of the solid plate is known as the efficiency of the joint and shall be calculated by the general method illustrated in the examples which follow:

In the examples the following notation is used:

TS = tensile strength stamped on plate, lb. per sq. in.
t = thickness of plate, in.
b = thickness of butt strap, in.
P = pitch of rivets, in., on row having greatest pitch
d = diameter of rivet after driving, in. = diameter of rivet hole
a = cross-sectional area of rivet after driving, sq. in.
s = shearing strength of rivet in single shear, lb. per sq. in., as given in Par. 16, page 2,177

S = shearing strength of rivet in double shear, lb. per sq. in., as given in Par. 16

c = crushing strength of mild steel, lb. per sq. in., as given in Par. 15

n = number of rivets in single shear in a unit length of joint

N = number of rivets in double shear in a unit length of joint.

Example 1.—Lap joint, longitudinal or circumferential, single-riveted (fig. 3,866).

A = strength of solid plate $= P\times t\times TS$

B = strength of plate between rivet holes $= (P-d)t\times TS$

C = shearing strength of one rivet in single shear $= n\times s\times a$

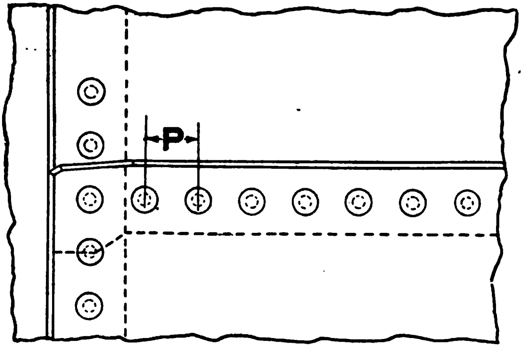


FIG. 3,866.—Example of lap joint, longitudinally, and circumferentially single riveted.

***A.S.M.E. Boiler Code.**—Ultimate strength of materials used in computing joints.*

12 Cast iron shall not be used for boiler and superheater mountings, such as nozzles, connecting pipes, fittings, valves and their bonnets, for steam temperatures of over 450 deg. Fahr.

14 *Tensile Strength of Steel Plate.* The tensile strength used in the computations for steel plates shall be that stamped on the plates as herein provided, which is the minimum of the stipulated range, or 55,000 lbs. per sq. in. for all steel plates, except for special grades having a lower tensile strength.

15 *Crushing Strength of Steel Plate.* The resistance to crushing of steel plate shall be taken at 95,000 lb. per sq. in. of cross-sectional area.

16 *Strength of Rivets in Shear.* In computing the ultimate strength of rivets in shear, the following values in pounds per square inch of the cross-sectional area of the rivet shank shall be used:

Iron rivets in single shear..........	38,000	Steel rivets in single shear...........	44,000
Iron rivets in double shear.........	76,000	Steel rivets in double shear..........	88,000

The cross-sectional area used in the computations shall be that of the rivet shank after driving.

D = crushing strength of plate in front of one rivet $= d \times t \times c$

Divide B, C or D (whichever is the least) by A, and the quotient will be the efficiency of a single-riveted lap joint as shown in fig. 3,866.

$TS = 55{,}000$ lb. per sq. in.
$t = \frac{1}{4}$ in. $= .25$ in.
$P = 1\frac{5}{8}$ in. $= 1.625$ in.
$d = \frac{11}{16}$ in. $= .6875$ in.
$a = .3712$ sq. in.
$s = 44{,}000$ lb. per sq. in.

$c = 95{,}000$ lb. per sq. in.
$A = 1.625 \times .25 \times 55{,}000 = 22{,}343$
$B = (1.625 - .6875)\ .25 \times 55{,}000 = 12{,}890$
$C = 1 \times 44{,}000 \times .3712 = 16{,}332$
$D = .6875 \times .25 \times 95{,}000 = 16{,}328$

$$\frac{12{,}890\ (B)}{22{,}343\ (A)} = .576 = \text{efficiency of joint}$$

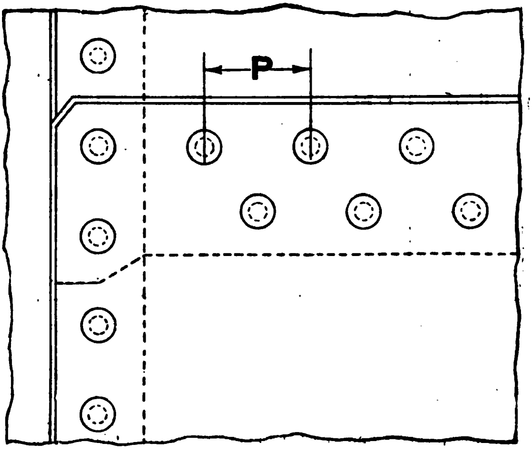


FIG. 3,867.—Example of lap joint, longitudinally and circumferentially double riveted.

Example 2.—Lap joint, longitudinal or circumferential, double-riveted (fig. 3,867).

A = strength of solid plate $= P \times t \times TS$
B = strength of plate between rivet holes $= (P - d)\ t \times TS$
C = shearing strength of two rivets in single shear $= n \times s \times a$
D = crushing strength of plate in front of two rivets $= n \times d \times t \times c$

Divide B, C, or D (whichever is the least) by A, and the quotient will be the efficiency of a double-riveted lap joint, as shown in fig. 3,867.

$TS = 55{,}000$ lb. per sq. in.
$t = \frac{5}{16}$ in. $= .3125$ in.
$P = 2\frac{7}{8}$ in. $= 2.875$ in.
$d = \frac{3}{4}$ in. $= .75$ in.
$a = .4418$ sq. in.
$s = 44{,}000$ lb. per sq. in.

$c = 95{,}000$ lb. per sq. in.
$A = 2.875 \times 0.3125 \times 55{,}000 = 49{,}414$
$B = (2.875 - .75)\ .3125 \times 55{,}000 = 36{,}523$
$C = 2 \times 44{,}000 \times .4418 = 38{,}878$
$D = 2 \times .75 \times .3125 \times 95{,}000 = 44{,}531$

$$\frac{36{,}523\ (B)}{49{,}414\ (A)} = .739 = \text{efficiency of joint}$$

Example 3.—Butt and double-strap joint, double-riveted (fig. 3,868).

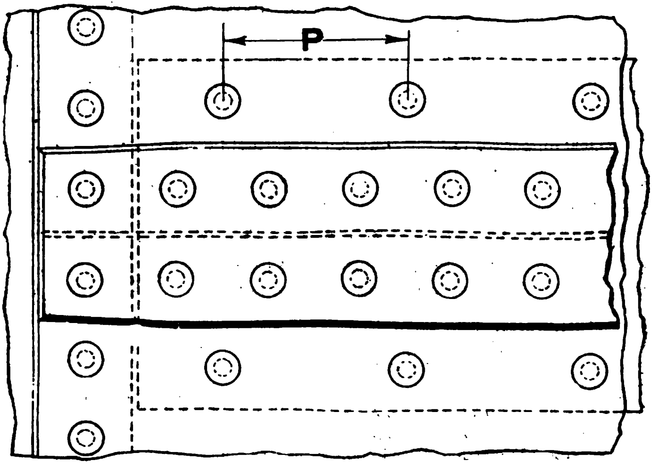


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Fig. 3,868.—Example of butt and double strap joint, double riveted.

A = strength of solid plate $= P \times t \times TS$

B = strength of plate between rivet holes in the outer row $= (P - d)\ t \times TS$

C = shearing strength of two rivets in double shear, plus the shearing strength of one rivet in single shear $= N \times S \times a + n \times s \times a$

D = strength of plate between rivet holes in the second row, plus the shearing strength of one rivet in single shear in the outer row $= (P - 2d)\ t \times TS + n \times s \times a$

E = strength of plate between rivet holes in the second row, plus the crushing strength of butt strap in front of one rivet in the outer row = $(P-2d)\,t\times TS+d\times b\times c$

F = crushing strength of plate in front of two rivets, plus the crushing strength of butt strap in front of one rivet = $N\times d\times t\times c+n\times d\times b\times c$

G = crushing strength of plate in front of two rivets, plus the shearing strength of one rivet in single shear = $N\times d\times t\times c+n\times s\times a$

H = strength of butt straps between rivet holes in the inner row = $(P-2d)\,2b\times TS$. This method of failure is not possible for thicknesses of butt straps required by these rules and the computation need only be made for old boilers in which thin butt straps have been used. For this reason this method of failure will not be considered in other joints.

Divide B, C, D, E, F, G or H (whichever is the least) by A, and the quotient will be the efficiency of a butt and double strap joint, double-riveted, as shown in fig. 3,868.

TS = 55,000 lb. per sq. in.
$t = \frac{3}{8}$ in. = .375 in.
$b = \frac{5}{16}$ in. = .3125 in.
$P = 4\frac{7}{8}$ in. = 4.875 in.
$d = \frac{7}{8}$ in. = .875 in.

a = .6013 sq. in.
s = 44,000 lb. per sq. in.
S = 88,000 lb. per sq. in.
c = 95,000 lb. per sq. in.

Number of rivets in single shear in a unit length of joint = 1.
Number of rivets in double shear in a unit length of joint = 2.

$A = 4.875\times .375\times 55{,}000 = 100{,}547$
$B = (4.875-.875)\ .375\times 55{,}000 = 82{,}500$
$C = 2\times 88{,}000\times .6013+1\times 44{,}000\times .6013 = 132{,}286$
$D = (4.875-2\times .875)\ .375\times 55{,}000+1\times 44{,}000\times .6013 = 90{,}910$
$E = (4.875-2\times .875)\ .375\times 55{,}000+.875\times .3125\times 95{,}000 = 90{,}429$
$F = 2\times .875\times .375\times 95{,}000+.875\times .3125\times 95{,}000 = 88{,}320$
$G = 2\times .875\times .375\times 95{,}000+1\times 44{,}000\times .6013 = 88{,}800$

$$\frac{82{,}500\ (B)}{100{,}547\ (A)} = .82 = \text{efficiency of joint}$$

Example 4.—Butt and double strap joint, triple-riveted (fig. 3,869).

A = strength of solid plate = $P\times t\times TS$

B = strength of plate between rivet holes in the outer row = $(P-d)\,t\times TS$

C = shearing strength of four rivets in double shear, plus the shearing strength of one rivet in single shear = $N\times S\times a+n\times s\times a$

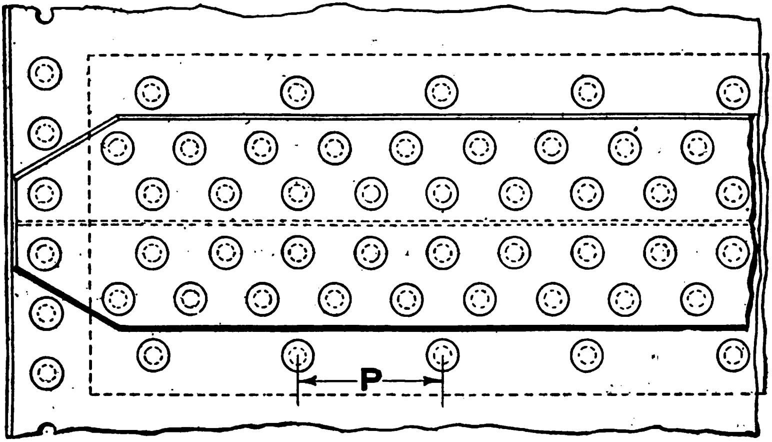
D = strength of plate between rivet holes in the second row, plus the shearing strength of one rivet in single shear in the outer row $=(P-2d)\, t\times TS+n\times s\times a$

E = strength of plate between rivet holes in the second row, plus the crushing strength of butt strap in front of rivet in the outer row $=(P-2d)\, t\times TS+d\times b\times c$

F = crushing strength of plate in front of four rivets, plus the crushing strength of butt strap in front of one rivet $=N\times d\times t\times c+n\times d\times b\times c$

C = crushing strength of plate in front of four rivets, plus the shearing strength of one rivet in single shear $=N\times d\times t\times c+n\times s\times a$

Divide B, C, D, E, F or G (whichever is the least) by A, and the quotient will be the efficiency of a butt and double strap joint, triple-riveted, as shown in fig. 3,869.



IG. 3,869.—Example of butt and double strap joint, triple riveted.

TS = 55,000 lb. per sq. in.

$t = \frac{3}{8}$ in. = .375 in.

$b = \frac{5}{16}$ in. = .3125 in.

$P = 6\frac{1}{2}$ in. = 6.5 in.

$d = \frac{13}{16}$ in. = .8125 in.

a = .5185 sq. in.

s = 44,000 lb. per sq. in.

S = 88,000 lb. per sq. in.

c = 95,000 lb. per sq. in.

Number of rivets in single shear in a unit length of joint = 1.

Number of rivets in double shear in a unit length of joint = 4.

$A = 6.5 \times .375 \times 55{,}000 = 134{,}062$

$B = (6.5 - .8125)\ .375 \times 55{,}000 = 117{,}304$

$C = 4 \times 88{,}000 \times .5185 + 1 \times 44{,}000 \times .5185 = 205{,}326$

$D = (6.5 - 2 \times .8125)\ .375 \times 55{,}000 + 1 \times 44{,}000 \times .5185 = 123{,}360$

$E = (6.5 - 2 \times .8125)\ .375 \times 55{,}000 + .8125 \times .3125 \times 95{,}000 = 124{,}667$

$F = 4 \times .8125 \times .375 \times 95{,}000 + 1 \times .8125 \times .3125 \times 95{,}000 = 139{,}902$

$G = 4 \times .8125 \times .375 \times 95{,}000 + 1 \times 44{,}000 \times .5185 = 138{,}595$

$$\frac{117{,}304\ (B)}{134{,}062\ (A)} = .875 = \text{efficiency of joint}$$

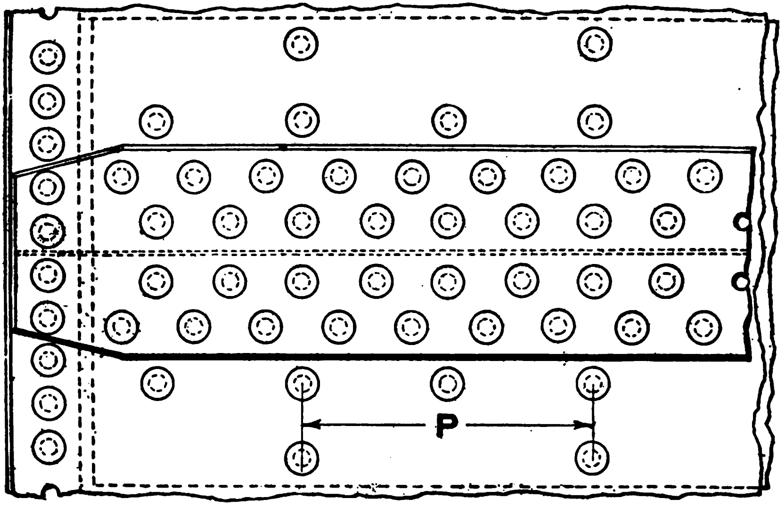


FIG. 3,870.—Example of butt and double strap joint, quadruple riveted.

Example 5.—Butt and double strap joint, quadruple riveted (fig. 3,870.)

A = strength of solid plate = $P \times t \times TS$

B = strength of plate between rivet holes in the outer row = $(P - d)t \times TS$

C = shearing strength of eight rivets in double shear, plus the shearing strength of three rivets in single shear = $N \times S \times a + n \times s \times a$

D = strength of plate between rivet holes in the second row, plus the shearing strength of one rivet in single shear in the outer row = $(P - 2d)\ t \times TS + 1 \times s \times a$

E = strength of plate between rivet holes in the third row, plus the shearing strength of two rivets in the second row in single shear and one rivet in single shear in the outer row = $(P-4d)t\times TS+n\times s\times a$

F = strength of plate between rivet holes in the second row, plus the crushing strength of butt strap in front of one rivet in the outer row = $(P-2d)t\times TS+d\times b\times c$

G = strength of plate between rivet holes in the third row, plus the crushing strength of butt strap in front of two rivets in the second row and one rivet in the outer row = $(P-4d)\ t\times TS+n\times d\times b\times c$

H = crushing strength of plate in front of eight rivets, plus the crushing strength of butt strap in front of three rivets = $N\times d\times t\times c+n\times d\times b\times c$

I = crushing strength of plate in front of eight rivets, plus the shearing strength of two rivets in the second row and one rivet in the outer row, in single shear = $N\times d\times t\times c+n\times s\times a$

Divide B, C, D, E, F, G, H or I (whichever is the least), by A, and the quotient will be the efficiency of a butt and double strap joint quadruple-riveted, as shown in fig. 3,870.

TS = 55,000 lb. per sq. in.
$t = \frac{1}{2}$ in. = .5 in.
$b = \frac{7}{16}$ in. = .4375 in.
P = 15 in.
$d = \frac{15}{16}$ in. = .9375 in.

a = .6903 sq. in.
s = 44,000 lb. per sq. in.
S = 88,000 lb. per sq. in.
c = 95,000 lb. per sq. in.

Number of rivets in single shear in a unit length of joint = 3.

Number of rivets in double shear in a unit length of joint = 8.

A.S.M.E. Boiler Code.—Riveting and Calking.

253 *Riveting.* Rivet holes, except for attaching stays or angle bars to heads, shall be drilled full size with plates, butt straps and heads bolted in position; or they may be punched not to exceed $\frac{1}{4}$ in. less than full diameter for plates over $\frac{5}{16}$ in. in thickness, and $\frac{1}{8}$ in. less than full diameter for plates not exceeding $\frac{5}{16}$ in. in thickness, and then drilled or reamed to full diameter with plates, butt straps and heads bolted in position.

254 After drilling rivet holes, the plates and butt straps shall be separated and the burrs removed.

255 *Rivets.* Rivets shall be of sufficient length to completely fill the rivet holes and form heads at least equal in strength to the bodies of the rivets.

256 Rivets shall be machine driven wherever possible, with sufficient pressure to fill the rivet holes, and shall be allowed to cool and shrink under pressure.

CAULKING

257 *Caulking.* The caulking edges of plates, butt straps and heads shall be beveled. Every portion of the caulking edges of plates, butt straps and heads shall be planed, milled or chipped to a depth of not less than $\frac{1}{8}$ in. Caulking shall be done with a round-nosed tool.

$A = 15 \times .5 \times 55{,}000 = 412{,}500$

$B = (15 - .9375)\ .5 \times 55{,}000 = 386{,}718$

$C = 8 \times 88{,}000 \times .6903 + 3 \times 44{,}000 \times .6903 = 577{,}090$

$D = (15 - 2 \times .9375)\ .5 \times 55{,}000 + 1 \times 44{,}000 \times .6903 = 391{,}310$

$E = (15 - 4 \times .9375)\ .5 \times 55{,}000 + 3 \times 44{,}000 \times .6903 = 400{,}494$

$F = (15 - 2 \times .9375)\ .5 \times 55{,}000 + .9375 \times .4375 \times 95{,}000 = 399{,}902$

$G = (15 - 4 \times .9375)\ .5 \times 55{,}000 + 3 \times .9375 \times .4375 \times 95{,}000 = 426{,}269$

$H = 8 \times .9375 \times .5 \times 95{,}000 + 3 \times .9375 \times .4375 \times 95{,}000 = 473{,}145$

$I = 8 \times .9375 \times .5 \times 95{,}000 + 3 \times 44{,}000 \times .6903 = 447{,}369$

$$\frac{386{,}718\ (B)}{412{,}500\ (A)} = .937 = \text{efficiency of joint}$$

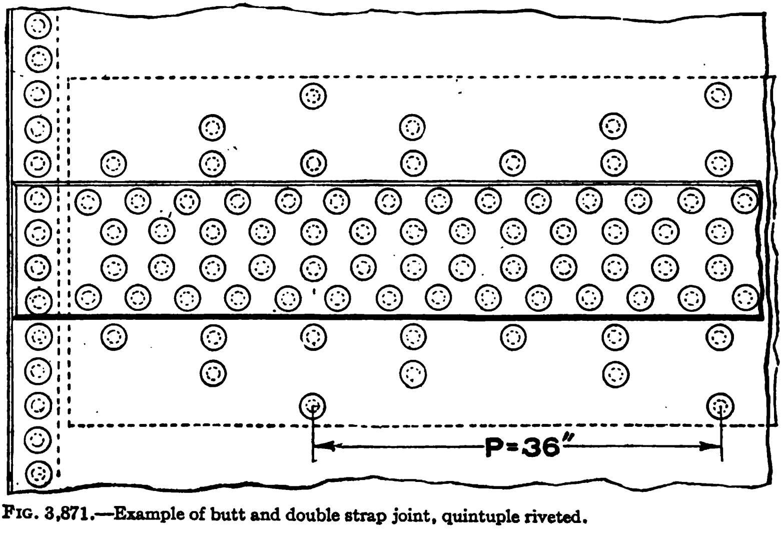


FIG. 3,871.—Example of butt and double strap joint, quintuple riveted.

Example 6.—Butt and double strap joint, quintuple-riveted (figs. 3,871 and 3,872).

A = strength of solid plate = $P \times t \times TS$

B = strength of plate between rivet holes in the outer row = $(P - d)\ t \times TS$

C = shearing strength of 16 rivets in double shear, plus the shearing strength of seven rivets in single shear $= N \times S \times a + n \times s \times a$

D = strength of plate between rivet holes in the second row, plus the shearing strength of one rivet in single shear in the outer row $= (P - 2d)\ t \times TS + 1 \times s \times a$

E = strength of plate between rivet holes in the third row, plus the shearing strength of two rivets in the second row in single shear and one rivet in single shear in the outer row $= (P - 4d)\ t \times TS + 3 \times s \times a$

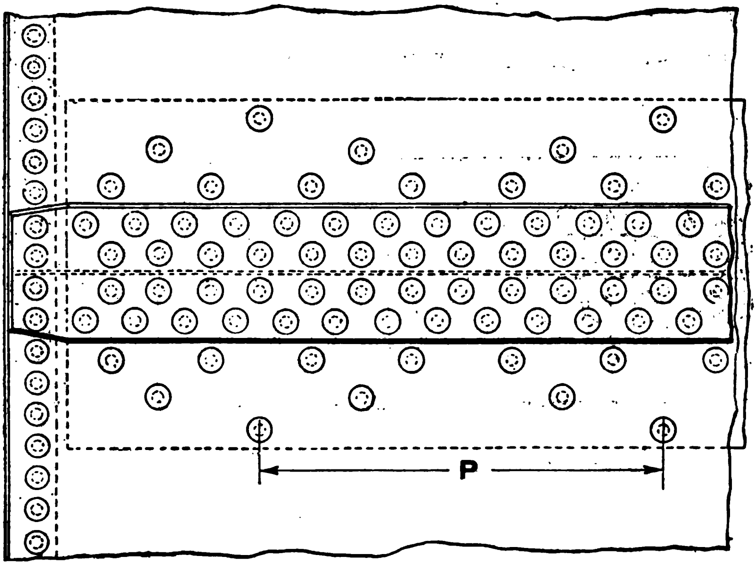


FIG. 3,872.—Example of butt and double strap joint, quintuple riveted.

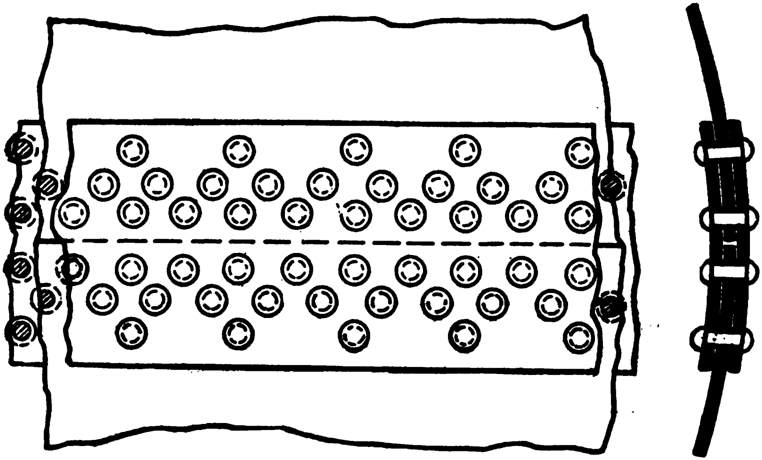
F = strength of plate between rivet holes in the fourth row, plus the shearing strength of four rivets in the third row, two rivets in the second row and one rivet in the outer row in single shear $= (P - 8d)\ t \times TS + n \times s \times a$

G = strength of plate between rivet holes in the second row, plus the crushing strength of butt strap in front of one rivet in the outer row $= (P - 2d)\ t \times TS + d \times b \times c$

H = strength of plate between rivet holes in the third row, plus the crushing strength of butt strap in front of two rivets in the second row and one rivet in the outer row $= (P-4d)\ t\times TS+3\times d\times b\times c$

I = strength of plate between rivet holes in the fourth row, plus the crushing strength of butt strap in front of four rivets in the third row, two rivets in the second row and one rivet in the outer row $= (P-8d)\ t\times TS+n\times d\times b\times c$

J = crushing strength of plate in front of 16 rivets, plus the crushing strength of butt strap in front of seven rivets $= N\times d\times t\times c+n\times d\times b\times c$



FIGS. 3,873 and 3,874.—Illustration of butt and double strap joint with straps of equal width.

K = crushing strength of plate in front of 16 rivets, plus the shearing strength of four rivets in the third row, two rivets in the second row and one rivet in the outer row in single shear $= N\times d\times t\times c+n\times s\times a$

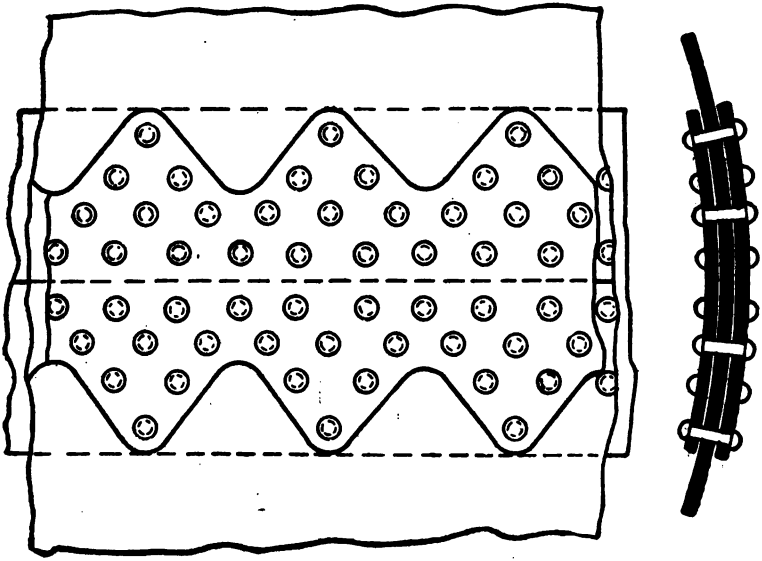
Divide B, C, D, E, F, G, H, I, J or K (whichever is the least), by A, and the quotient will be the efficiency of a butt and double strap joint, quintuple-riveted, as shown in fig. 3,871 or fig. 3,872.

$TS = 55{,}000$ lb. per sq. in.
$t = \frac{3}{4}$ in. $= 0.75$ in.
$b = \frac{1}{2}$ in. $= 0.5$ in.
$a = 1.3529$ sq. in.
$s = 44{,}000$ lb. per sq. in.
$S = 88{,}000$ lb. per sq. in.

$P = 36$ in.
$d = 1\frac{5}{16}$ in. $= 1.3125$ in.
$a = 1.3529$ sq. in.
$s = 44{,}000$ lb. per sq. in.
$S = 88{,}000$ lb. per sq. in.
$c = 95{,}000$ lb. per sq. in.

Number or rivets in single shear in a unit length of joint = 7.
Number of rivets in double shear in a unit length of joint = 16.

$A = 36 \times .75 \times 55{,}000 = 1{,}485{,}000$
$B = (36 - 1.3125)\ .75 \times 55{,}000 = 1{,}430{,}860$
$C = 16 \times 88{,}000 \times 1.3529 + 7 \times 44{,}000 \times 1.3529 = 2{,}321{,}576$
$D = (36 - 2 \times 1.3125)\ .75 \times 55{,}000 + 1 \times 44{,}000 \times 1.3529 = 1{,}436{,}246$
$E = (36 - 4 \times 1.3125)\ .75 \times 55{,}000 + 3 \times 44{,}000 \times 1.3529 = 1{,}447{,}020$
$F = (36 - 8 \times 1.3125)\ .75 \times 55{,}000 + 7 \times 44{,}000 \times 1.3529 = 1{,}468{,}568$



Figs. 3,875 and 3,876.—Illustration of butt and double strap joint of the saw tooth type.

$G = (36 - 2 \times 1.3125)\ .75 \times 55{,}000 + 1.3125 \times .5 \times 95{,}000 = 1{,}439{,}064$
$H = (36 - 4 \times 1.3125)\ .75 \times 55{,}000 + 3 \times 1.3125 \times .5 \times 95{,}000 = 1{,}455{,}472$
$I = (36 - 8 \times 1.3125)\ .75 \times 55{,}000 + 7 \times 1.3125 \times .5 \times 95{,}000 = 1{,}488{,}141$
$J = 16 \times 1.3125 \times .75 \times 95{,}000 + 7 \times 1.3125 \times .5 \times 95{,}000 = 1{,}932{,}266$
$K = 16 \times 1.3125 \times .75 \times 95{,}000 + 7 \times 44{,}000 \times 1.3529 = 1{,}912{,}943$

$$\frac{1{,}430{,}860\ (B)}{1{,}485{,}000\ (A)} = .963 = \text{efficiency of joint}$$

Figs. 3,873 to 3,876 illustrate other joints that may be used. The butt and double strap joint with straps of equal width shown in figs. 3,873 and 3,874 may be so designed that it will have an efficiency of 82 to 84 per cent and the saw tooth joint (figs. 3,875 and 3,876), an efficiency of from 92 to 94 per cent.

The following tables give details of riveted joints for different thicknesses of plate as recommended by the Wickes Boiler Co.

Lap Joints

Thickness of Plate, Inches	Diameter of Rivet, Inches	Center of Hole to Edge of Plate Inches	Single Riveted			Double Riveted				
			Pitch Inches	Lap Inches	Efficiency of Plate Per Cent.	Diameter of Rivet Inches	Pitch Inches	Lap Inches	Between Rows Inches	Efficiency of Plate Per Cent.
5/16	11/16	1 1/8	1 3/4	2 1/4	57.1	11/16	2 3/4	3 9/16	1 13/16	72.7
11/32	3/4	1 7/32	1 7/8	2 7/16	56.6	3/4	2 15/16	4 1/8	2 3/16	72.3
3/8	13/16	1 11/32	2	2 11/16	56.2	13/16	3 1/8	5	2 5/16	72.0
13/32	7/8	1 13/32	2 1/8	2 13/16	55.8	7/8	3 1/4	5	2 5/16	71.1
7/16	15/16	1 1/2	2 1/4	3	55.5	15/16	3 3/8	5 9/16	2 5/16	70.3
15/32	1	1 19/32	2 7/16	3 3/16	56.4	15/16	3 1/2	5 7/16	2 1/4	71.4
1/2	1	1 19/32	2 5/16	3 3/16	54.0	1	3 5/8	5 7/16	2 1/4	70.6

Triple Riveted Butt Strap Joint

Thickness of Plate Inches	Diameter of Rivet Inches	Pitch of Rivets in Inches	Width of Outside Butt Strap	Width of Inside Butt Strap	Thickness of Cover Straps	Vertical or Trans. Pitch	Edge of Butt Strap to Center of Rivets	Efficiency of Plate Per Cent.
5/16	11/16	3 1/8 x 6 1/4	9 1/4	14	1/4	2 1/4	1 1/8	88
11/32	11/16	3 1/4 x 6 1/2	9 1/2	14	1/4	2 1/4	1 1/8	88.5
3/8	3/4	3 3/8 x 6 3/4	9 1/2	14 1/2	5/16	2 5/16	1 7/32	87.9
13/32	3/4	3 1/2 x 7	9 1/2	14 1/2	5/16	2 5/16	1 7/32	88.4
7/16	13/16	3 5/8 x 7 1/4	9 3/4	15 1/2	3/8	2 3/8	1 5/16	87.9
15/32	7/8	3 3/4 x 7 1/2	10 1/4	15 5/8	13/32	2 3/8	1 13/32	87.5
1/2	7/8	3 7/8 x 7 3/4	10 1/4	15 5/8	7/16	2 3/8	1 13/32	87.8

Quadruple Riveted Butt Strap Joint

Thickness of Plate Inches	Diameter of Rivet Inches	Pitch of Rivets in Inches	Width of Outside Butt Strap	Width of Inside Butt Strap	Thickness of Cover Straps	Vertical or Trans. Pitch	Edge of Butt Strap to Center of Rivets	Efficiency of Plate Per Cent.
3/8	3/4	7 1/4 x 14 1/2	9 1/2	20 5/8	5/16	2 3/16	1 7/32	94.4
13/32	3/4	7 3/8 x 14 3/4	9 1/2	20 5/8	5/16	2 3/16	1 7/32	94.5
7/16	13/16	7 1/2 x 15	9 3/4	22	3/8	2 1/4	1 5/16	94.2
15/32	7/8	8 x 16	10 1/4	22 1/2	13/32	2 1/4	1 13/32	94.1
1/2	7/8	8 x 16	10 1/4	22 1/2	7/16	2 1/4	1 13/32	94.1

A.S.M.E. Boiler Code.—Specifications for boiler rivet steel.

51. *Marking.* Rivet bars shall, when loaded for shipment, be properly separated and marked with the name or brand of the manufacturer and the melt number for identification. The melt number shall be legibly marked on each test specimen.

U.S. Marine Rules.—Riveted joints.

9. The diameter of rivets, rivet holes, distance between centers of rivets, and distance from centers of rivets to edge of lap for different thicknesses of plates for single and double riveting shall be determined by the following rules.

The following formulas, equivalent to those of the British Board of Trade, are given for the determination of the pitch, distance between rows of rivets, diagonal pitch, maximum pitch, and distance from centers of rivets to edge of lap of single and double riveted lap joints, for both iron and steel boilers:

Let p = greatest pitch of rivets in inches.
n = number of rivets in one pitch.
p_d = diagonal pitch in inches.
d = diameter of rivets in inches.
T = thickness of plate in inches.
V = distance between rows of rivets in inches.
E = distance from edge of plate to center of rivet in inches.

TO DETERMINE THE PITCH

Iron plates and iron rivets:

$$p = \frac{d^2 \times .7854 \times n}{T} + d.$$

Example, first, for single-riveted joint: Given, thickness of plate (T) = $\frac{1}{2}$ inch, diameter of rivet (d) = $\frac{7}{8}$ inch. In this case $n = 1$. Required the pitch.

Substituting in formula, and performing operation indicated,

$$\text{Pitch} = \frac{(\frac{7}{8})^2 \times .7854 \times 1}{\frac{1}{2}} + \frac{7}{8} = 2.077 \text{ inches}$$

Example for double-riveted joint: Given, $t = \frac{1}{2}$ inch and $d = \frac{13}{16}$ inch. In this case $n = 2$. Then—

$$\text{Pitch} = \frac{(\frac{13}{16})^2 \times .7854 \times 2}{\frac{1}{2}} + \frac{13}{16} = 2.886 \text{ inches.}$$

For *steel* plates and steel rivets:

$$p = \frac{23 \times d^2 \times .7854 \times n}{28 \times T} + d.$$

Example for single-riveted joint: Given, thickness of plate = $\frac{1}{2}$ inch, diameter of rivet = $\frac{15}{16}$ inch. In this case $n = 1$.

$$\text{Pitch} = \frac{23 \times (\frac{15}{16})^2 \times .7854 \times 1}{28 \times \frac{1}{2}} + \frac{15}{16} = 2.071 \text{ inches}$$

Example for double-riveted joint: Given thickness of plate = $\frac{1}{2}$ inch, diameter of rivet, = $\frac{7}{8}$ inch. $n = 2$. Then—

$$\text{Pitch} = \frac{23 \times (\frac{7}{8})^2 \times .7854 \times 2}{28 \times \frac{1}{2}} + \frac{7}{8} = 2.85 \text{ inches.}$$

FOR DISTANCE FROM CENTER OF RIVET TO EDGE OF LAP.

$$E = \frac{3 \times d}{2}.$$

Example: Given, diameter of rivet (d) = $\frac{7}{8}$ inch; required the distance from center of rivet to edge of plate.

$E = \frac{3 \times \frac{7}{8}}{2} = 1.312$ inches, for single or double riveted lap joint.

U.S. Marine Rules.—Riveted Joints.—Continued.

FOR DISTANCE BETWEEN ROWS OF RIVETS.

The distance between lines of centers of rows of rivets for double, chain-riveted joints (V) shall not be less than twice the diameter of rivet, but it is more desirable that V should not be less than

$$\frac{4d+1}{2}.$$

Example under latter formula: Given, diameter of rivet $= \frac{7}{8}$ inch, Then—

$$V = \frac{(4\times\frac{7}{8})+1}{2} = 2.25 \text{ inches.}$$

For ordinary, double, zigzag riveted joints:

$$V = \frac{\sqrt{(11p+4d)\quad(p+4d)}}{10}$$

Example: Given, pitch $= 2.85$ inches, and diameter of rivet $= \frac{7}{8}$ inch, Then—

$$V = \frac{\sqrt{11\times2.85+4\times\frac{7}{8})\quad(2.85+4\times\frac{7}{8})}}{10} = 1.487 \text{ inches.}$$

DIAGONAL PITCH.

For double, zigzag riveted lap joint. Iron and steel:

$$p_d = \frac{6p+4d}{10}$$

Example: Given, pitch $= 2.85$ inches, and $d = \frac{7}{8}$ inch. Then—

$$p_d = \frac{(6\times2.85)+(4\times\frac{7}{8})}{10} = 2.06 \text{ inches.}$$

MAXIMUM PITCHES FOR RIVETED LAP JOINTS.

For single-riveted lap joints:

$$\text{Maximum pitch} = (1.31\times T)+1\tfrac{5}{8}.$$

For double-riveted lap joints:

$$\text{Maximum pitch} = (2.62\times T)+1\tfrac{5}{8}.$$

Example: Given, a thickness of plate $= \frac{1}{2}$ inch, required the maximum pitch allowable. For single-riveted lap joint:

$$\text{Maximum pitch} = (1.31\times\tfrac{1}{2})+1\tfrac{5}{8} = 2.28 \text{ inches.}$$

For double-riveted lap joint:

$$\text{Maximum pitch} = (2.62\times\tfrac{1}{2})+1\tfrac{5}{8} = 2.935 \text{ inches.}$$

To determine the pitch of rivets from the above formulæ, use the diameter and area of the rivet holes. The diameter of the rivets is the diameter of the driven rivet.

Any riveted joint shall be allowed when it is constructed so as to give an equal percentage of strength to that obtained by the use of the formula given. (Secs. 4418, 4433, R. S.)

BUTT STRAPS.

10. Where butt straps are used in the construction of marine boilers, the straps for single butt strapping shall in no case be less than the thickness of the shell plates; and where double butt straps are used, the thickness of each shall in no case be less than five-eighths the thickness of the shell plates. (Sec. 4418, R. S.)

A.S.M.E. Boiler Code—Boiler Joints.

181 *Efficiency of a Joint.* The efficiency of a joint is the ratio which the strength of the joint bears to the strength of the solid plate. In the case of a riveted joint this is determined by calculating the breaking strength of a unit section of the joint, considering each possible mode of failure separately, and dividing the lowest result by the breaking strength of the solid plate of a length equal to that of the section considered.

182 The distance between the center lines of any two adjacent rows of rivets, or the "back pitch" measured at right angles to the direction of the joint, shall be at least twice the diameter of the rivets and shall also meet the following requirements:

a Where each rivet in the inner row comes midway between two rivets in the outer row, the sum of the two diagonal sections of the plate between the inner rivet and the two outer rivets shall be at least 20 per cent greater than the section of the plate between the two rivets in the outer row.

b Where two rivets in the inner row come between two rivets in the outer row, the sum of the two diagonal sections of the plate between the two inner rivets and the two rivets in the outer row shall be at least 20 per cent greater than the difference in the section of the plate between the two rivets in the outer row and the two rivets in the inner row.

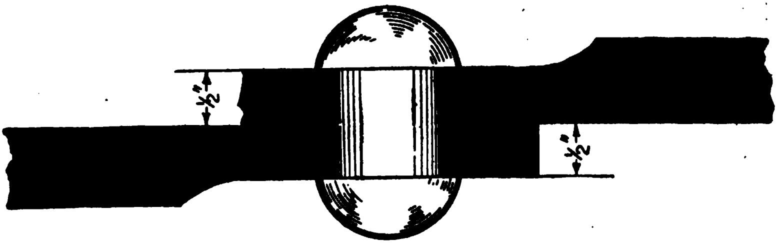


FIG. 3,877.—A.S.M.E. circumferential joint for thick plates of horizontal return tubular boilers.

183 On longitudinal joints, the distance from the centers of rivet holes to the edges of the plates, except rivet holes in the ends of butt straps, shall be not less than one and one-half times the diameter of the rivet holes.

184 *a* *Circumferential Joints.* The strength of circumferential joints of boilers, the heads of which are not stayed by tubes or through braces shall be at least 50 per cent of that of the longitudinal joints of the same structure.

b When 50 per cent or more of the load which would act on an unstayed solid head of the same diameter as the shell, is relieved by the effect of tubes or through stays, in consequence of the reduction of the area acted on by the pressure and the holding power of the tubes and stays, the strength of the circumferential joints in the shell shall be at least 35 per cent that of the longitudinal joints.

185 When shell plates exceed 9/16 inch in thickness in horizontal return tubular boilers, the portion of the plates forming the laps of the circumferential joints, where exposed to the fire or products of combustion, shall be planed or milled down as shown in fig. 3,877, to ½ inch in thickness, provided the requirement in par. 184 is complied with.

186 *Welded Joints.* The ultimate tensile strength of a longitudinal joint which has been properly welded by the forging process, shall be taken as 28,500 pounds per square inch, with steel plates having a range in tensile strength of 47,000 to 55,000 pounds per square inch.

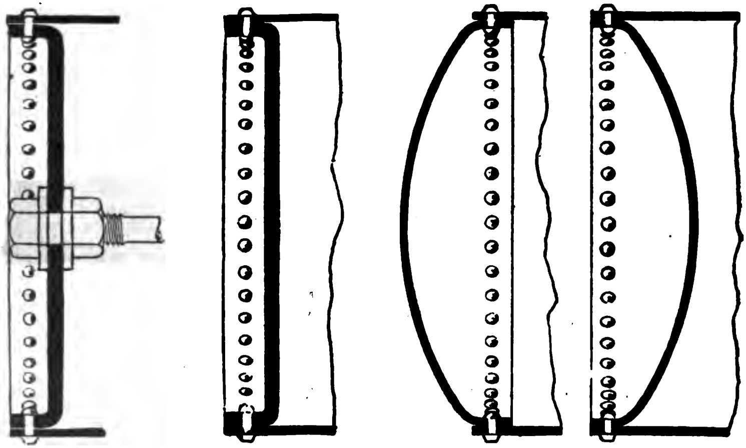
187 *Longitudinal Joints.* The longitudinal joints of a shell or drum which exceeds 36 inches in diameter, shall be of butt and double-strap construction.

188 The longitudinal joints of a shell or drum which does not exceed 36 inches in diameter, may be of lap-riveted construction; but the maximum allowable working pressure shall not exceed 100 pounds per square inch.

Boiler Heads.—These serve two purposes, 1, to close the ends of the boiler, and in the case of fire tube boilers to hold the ends of the tubes. There are two general classes of head as,

1. Flat.
2. Dished.

Examples belonging to the two classes are shown in figs. 3,878 to 3,881. In drums for water tube boilers, the flat form shown in figs. 3,878 and 3,879 is generally used,



Figs. 3,878 to 3,881.—Types of boiler head. Fig. 3,178, flat head with through stay; fig. 3,879, flat head without through stay; fig. 3,180, dished head with convex external side; fig 3,881, dished head with concave external side.

The dished form has greater strength and avoids the use of stays.

A.S.M.E. Boiler Code.—Boiler Joints.—Continued.

189 The longitudinal joints of horizontal return tubular boilers shall be located above the fire-line of the setting.

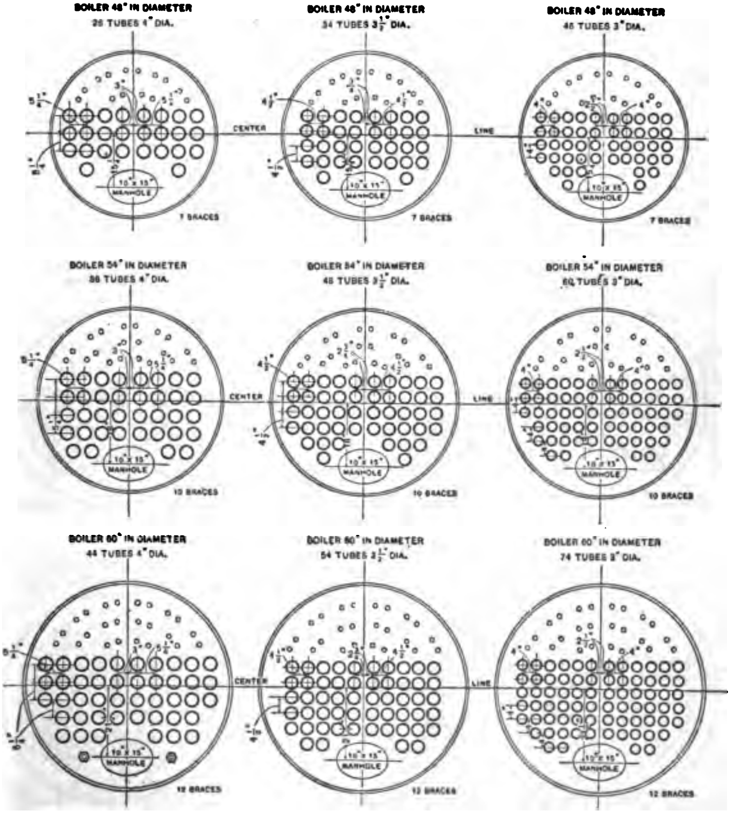
190 A horizontal return tubular boiler on which a longitudinal lap joint is permitted shall not have a course over 12 feet in length. With butt and double-strap construction, longitudinal joints of any length may be used provided the plates are tested transversely to the direction of rolling, which tests shall show the standards prescribed under the Specification ot Boiler Plate Steel.

191 Butt straps and the ends of shell plates forming the longitudinal joints shall be rolled or formed by pressure, not blows, to the proper curvature.

The flat flanged head is the type used in tubular boilers. Usually the flange of the head is placed inside the shell.

Tube Spacing.—The many causes of dangerous accumulation of sediment, scale and foreign matter which inspection brings out, makes it clear

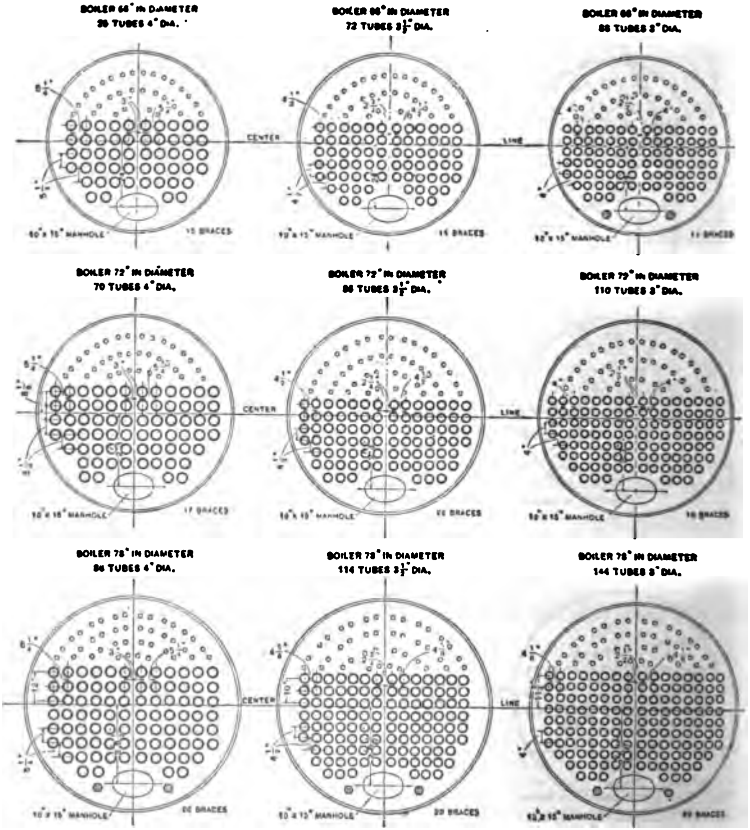
Tube Spacing 48 to 60 inch Boilers



Figs. 3,882 to 3,890.—Wickes standard layout of tubes and braces for horizontal tubular boilers with manhole in head, for ***48-inch to 60-inch boilers.***

that it is wiser that fewer tubes be used than was formerly the custom. Ample space should be left between the tubes and between the tubes and the shell and under the tubes for access at all times for the removal of foreign matter collected.

Tube Spacing 66 to 78 inch Boilers


BOILER 66" IN DIAMETER 56 TUBES 4" DIA.

BOILER 66" IN DIAMETER 72 TUBES 3½" DIA.

BOILER 66" IN DIAMETER 88 TUBES 3" DIA.

BOILER 72" IN DIAMETER 70 TUBES 4" DIA.

BOILER 72" IN DIAMETER 86 TUBES 3½" DIA.

BOILER 72" IN DIAMETER 110 TUBES 3" DIA.

BOILER 78" IN DIAMETER 84 TUBES 4" DIA.

BOILER 78" IN DIAMETER 114 TUBES 3½" DIA.

BOILER 78" IN DIAMETER 144 TUBES 3" DIA.

Figs. 3,891 to 3,899.—Wickes standard layout of tubes and braces for horizontal tubular boilers with manhole in head, *for 66-inch to 78-inch boilers.*

Figs 3,882 to 3,899 are examples of tube spacing for boilers ranging in size from 48 to 78 inches in diameter.

Ligaments.—When a head is drilled for tubes, a good deal of the metal is cut away, hence the efficiency of the metal between the tube holes or *ligament* must be considered.

There are two cases, according to the arrangement of the tubes.

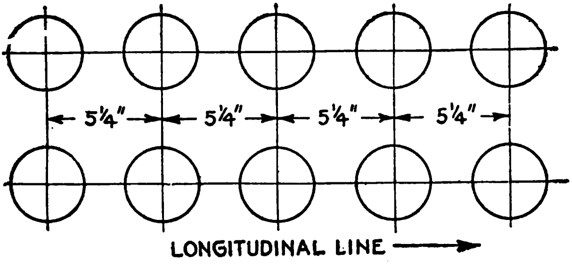


FIG. 3,900.—Example of tube spacing, with pitch of holes ***equal in every row***, illustrating ***efficiency of ligament.***

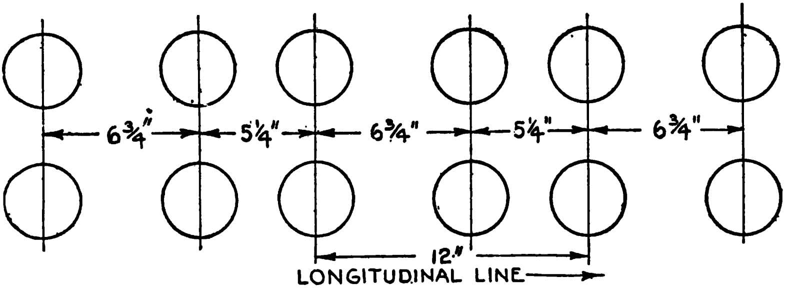


FIG. 3,901.—Example of tube spacing with pitch of holes ***unequal in every second row***, illustrating ***efficiency of ligament.***

1. *Holes drilled in line* **parallel** *to the axis of the shell* (figs. 3,900 to 3,902.)

A. Pitch of the tube holes in every row equal.

B. Pitch of the tube holes in any one row unequal.

2. Holes drilled in a line diagonal with the axis of the shell (fig. 3,903).

The methods of determining the efficiency of the ligament for the several cases are, according to the ***A.S.M.E. Boiler Code*** as follows:

A. *Pitch of the tube holes in every row* **equal** as shown in fig. 3,900.

$$\textit{efficiency of ligament} = \frac{p-d}{p}$$

where $\left\{ \begin{array}{l} p = \text{pitch of tube holes in inches} \\ d = \text{diameter of tube holes in inches} \end{array} \right.$

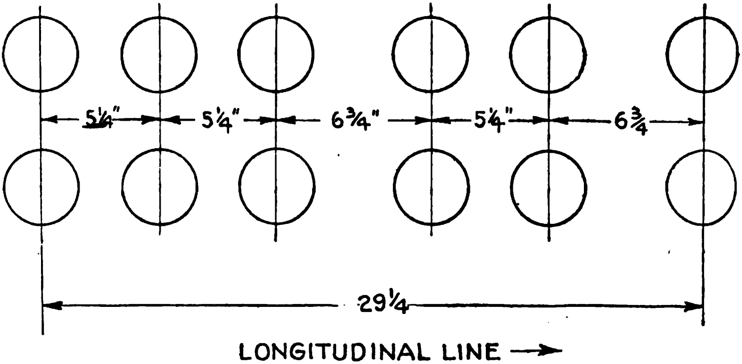


FIG. 3,902.—Example of tube spacing with pitch of holes ***varying in every second and third row***, illustrating ***efficiency of ligament***.

Example.—If the pitch of tube holes in the head shown in fig. 3,900 be 5¼ inches, diameter of tubes 3¼ inches, tube holes 3⁹⁄₃₂ inches, what is the efficiency of the ligament?

$$\textit{efficiency of ligament} = \frac{p-d}{p} = \frac{5\frac{1}{4}-3\frac{9}{32}}{5\frac{1}{4}} = \frac{5.25-3.281}{5.25} = .375$$

B. *Pitch of tube holes in any one row* **unequal,** as shown in figs. 3 901 and 3,902.

NOTE.—The Hartford Boiler Insurance Co. says, in regard to tube spacing: "In our experience we have found great difficulty with this arrangement of tubes (speaking of tubes closely put in), particularly when used with bad water. It gives a greater area of tube surface, but considerable portion of the surface so gained is useless, and worse than useless, from the fact that the water space is unduly taken up by the superfluous tubes."

$$\textit{efficiency of ligament} = \frac{p - nd}{p}$$

$$\text{where} \begin{cases} p = \text{unit length of ligament in inches} \\ n = \text{number of tube holes in length } p \\ d = \text{diameter of tube holes in inches} \end{cases}$$

Example.—If the diameter of tube holes be 3$\frac{9}{32}$, and the spacing be as shown in fig. 3,901, what is the efficiency of the ligament?

$$\textit{efficiency of ligament} = \frac{p - nd}{p} = \frac{12 - 2 \times 3.281}{12} = .453$$

Example.—What is the efficiency of ligament for the spacing shown in fig. 3,902, and 3$\frac{9}{32}$-inch holes?

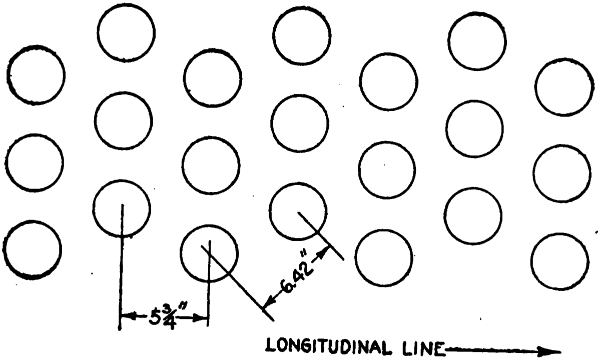


FIG. 3,903.—Example of tube spacing with ***tube holes on diagonal lines,*** illustrating ***efficiency of ligament.***

2. *Holes drilled in a line* **diagonal** *with the axes of the* shell as shown in fig. 3,903.

For this arrangement of tube holes the efficiency of the ligament shall be determined by the following methods and the lowest value used.

$$\textit{efficiency of ligament} = \begin{cases} a.\ \dfrac{.95(p_1 - d)}{p_1} \\ b.\ \dfrac{p - d}{p} \end{cases}$$

where
p_1 = diagonal pitch of tube holes in inches
d = diameter of tube holes in inches
p = longitudinal pitch of tube holes or distance between center of tubes in a longitudinal row in inches

The constant .95 in the formula a applies provided $p_1 \div d$ be 1.5 or over.

Example.—Diagonal pitch of tube holes, as shown in fig. 3,903 = 6.42 inches, diameter of holes, $4\frac{1}{32}$ inches, longitudinal pitch of holes, $11\frac{1}{2}$ inches.

$$a.\quad \frac{.95(6.42-4.031)}{6.42}=.353$$

$$b.\quad \frac{11.5-4.031}{11.5}=649$$

Taking the least value determined by formulae a and b, the efficiency of ligament is .355.

Area of Head to Be Stayed.—Where flat heads are used, it is necessary to provide stays or braces for that part unsupported by the tubes. For the water space the bracing afforded by the tubes is sufficient, although sometimes a few *stay tubes* with screw threads and lock nuts are provided to increase the bracing power; for the rest of the head it is necessary to provide sufficient bracing to resist the pressure.

A problem which presents itself is to find the area of the segment of the head to be braced, and it should be noted that this is a question often asked on examination papers for engineer's license.

A.S.M.E. Boiler Code.—Tubes.

248 *Tube Holes and Ends.* Tube holes shall be drilled full size from the solid plate, or they may be punched at least ½ inch smaller in diameter than full size, and then drilled, reamed or finished full size with a rotating cutter.

249 The sharp edges of tube holes shall be taken off on both sides of the plate with a file or other tool.

250 A fire-tube boiler shall have the ends of the tubes substantially rolled and beaded, or welded at the firebox or combustion chamber end.

251 The ends of all tubes, suspension tubes and nipples shall be flared not less than ⅛ in. over the diameter of the tube hole on all water-tube boilers and superheaters, or they may be beaded.

252 The ends of all tubes, suspension tubes and nipples of water-tube boilers and superheaters shall project through the tube sheets or headers not less than ¼ inch nor more than ½ inch before flaring.

Ques. What portion of the head not occupied by tubes must be stayed?

Ans. According to the A. S. M. E. Boiler Code the area of a segment of a head to be stayed shall be the area enclosed by lines

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U.S. Marine Rules—Heads.

REQUIREMENTS FOR HEADS.

3. All plates used as heads, when new and made to practically true circles, and as described below, shall be allowed a steam pressure in accordance with the following formula:

CONVEX HEADS.

$$P = \frac{T \times S}{R}$$

Where P = steam pressure allowable in pounds.
T = thickness of plate in inches.
S = one-fifth of the tensile strength.
R = one-half of the radius to which the head is bumped.

CONCAVE HEADS.

For concave heads the pressure allowable shall be eight-tenths times the pressure allowable for convex heads.

NOTE.—To find the radius of a sphere of which the bumped head forms a part, square the radius of head, divide this by the height of bump required; to the result add height of bump, which will equal diameter of sphere, one-half of which will be the required radius.

Example.

Required, the working pressure of a convex head of a 54-inch radius; material, 60,000 pounds tensile strength and one-half of an inch thick. Substituting values and solving, we have

$$P = \frac{.5 \times 12{,}000}{27} = 222 \text{ pounds.}$$

The pressure allowable on a concave head of the same dimensions would be 222×.8 = 177 pounds.

To avoid grooving the flanging shall be well rounded at the bend.

Bumped heads may contain a manhole opening flanged inwardly, when such flange is turned to a depth of three times the thickness of material in the head.

Material used in the construction of all bumped heads shall possess the physical and chemical qualities prescribed by the Board of Supervising Inspectors for all plates subject to tensile strain, as required by section 4430, Revised Statutes.

FLAT HEADS OF WROUGHT-IRON OR STEEL PLATE.

Where flat heads do not exceed 20 inches in diameter they may be used without being stayed, and the steam pressure allowable shall be determined by the following formula:

$$P = \frac{C \times T_2}{A}$$

drawn 3 inches from the shell and 2 inches from the tubes as shown in fig. 3,904 and 3,905.

The net area to be stayed in a segment of a head may be determined by the following formula:

$$\text{area of segment} = \frac{4(H-5)^2}{3}\sqrt{\frac{2(R-3)}{H-5}} \text{ square inches}$$

in which H = distance from tubes to shell, and R = radius of boiler head both in inches.

When the portion of the head below the tubes (lower segment), in a

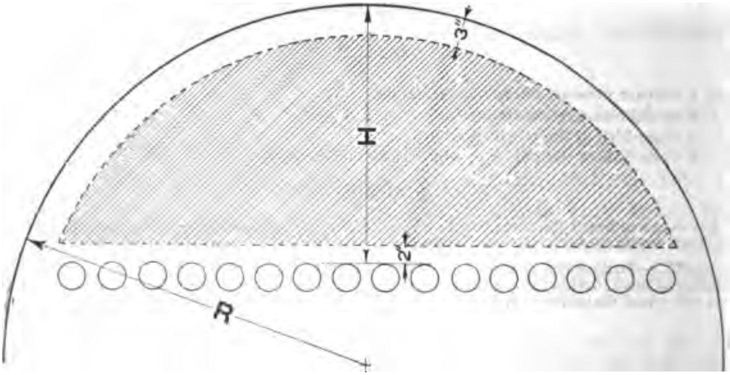

FIG. 3,904.—Upper segment of head to be stayed.

U. S. Marine Rules.—Heads—Continued.

Where P = steam pressure allowable in pounds.
T = thickness of material in sixteenths of an inch.
A = one-half the area of head in inches.
C = 112 for plates seven-sixteenths of an inch and under.
C = 120 for plates over seven-sixteenths of an inch.

Provided, The flanges are made to an inside radius of at least 1½ inches.

Example.

Required the working pressure of a flat head 20 inches in diameter and three-fourths of an inch thick. Substituting values, we have

$$P = \frac{120 \times 144}{157} = 110 \text{ pounds.}$$

(Sec. 4418, R. S.)

horizontal return tubular boiler is provided with manhole opening, the flange of which is formed from the solid plate and turned inward to a depth of not less than three times the thickness of the head, measured from the outside, the area to be stayed as shown in fig. 3,905, may be reduced by 100 square inches. The surface around the manhole shall be supported by through stays with nuts inside and outside at the front head (*A.S.M.E. Boiler Code*).

Reinforcement of Flat Surfaces.—All flat surfaces in boilers must be stiffened or supported, otherwise the internal pressure of the steam would bulge them outward and tend to make them

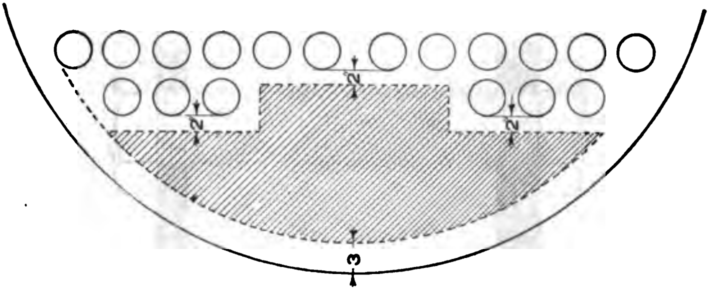

FIG. 3,905.—Lower segment of head to be stayed.

***A.S.M.E. Boiler Code.**—Braced and Stayed Surfaces.*

199 The maximum allowable working pressure for various thicknesses of braced and stayed flat plates and those which by these Rules require staying as flat surfaces with braces or staybolts of uniform diameter symmetrically spaced, shall be calculated by the formula:

$$P = C \times \frac{t^2}{p^2}$$

where

P = maximum allowable working pressure, pounds per square inch.
t = thickness of plate in *sixteenths* of an inch
P = maximum pitch measured between straight lines passing through the centers of the staybolts in the different rows, which lines may be horizontal, vertical or inclined, inches
C = 112 for stays screwed through plates not over 7/16 inch thick with ends riveted over
C = 120 for stays screwed through plates over 7/16 inch thick with ends riveted over
C = 135 for stays screwed through plates and fitted with single nuts outside of plate
C = 175 for stays fitted with inside and outside nuts and outside washers where the diameter of washers is not less than $.4p$ and thickness not less than t.

If flat plates not less than 3/8 inch thick are strengthened with doubling plates securely riveted thereto and having a thickness of not less than 2/3 t, nor more than t, then the value of t in the formula shall be 3/4 of the combined thickness of the plates and the values of C given above may also be increased 15 per cent.

spherical or cylindrical in shape. This reinforcement is obtained by means of stays and braces.

By common usage, the difference between stays and braces seems to be chiefly one of size, that is, a brace is a large stay.*

Ques. Into what two classes may all of reinforcing members be divided?

Ans. They may be classed as *independent* and *connecting* fastenings.

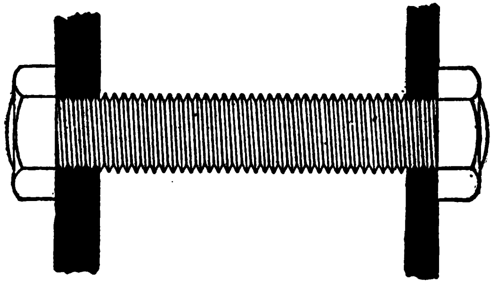

FIG. 3,906.—Stay bolt, consisting of a threaded length of rod with a nut at each end, or a forged head at one end and a nut at the other end.

Stay Bolts.—The term "bolt" is defined as *a metallic pin or rod, used to hold objects together and generally having screw threads cut at one end, and sometimes at both, to receive a* **nut.**

The author regards a nut as forming part of a bolt and therefore restricts the term *stay bolt* to the type of stay shown in fig. 3,906.

It consists of a rod having a thread its entire length and a nut on each end. This kind of stay is used in making repairs but owing to the extra amount of metal in the nut is not so well adapted to the intense heat in the firebox as the riveted stays shown in figs. 3,915 and 3,916. It is suitable for less severe conditions as for staying the steam jacketed uptake in marine leg boilers.

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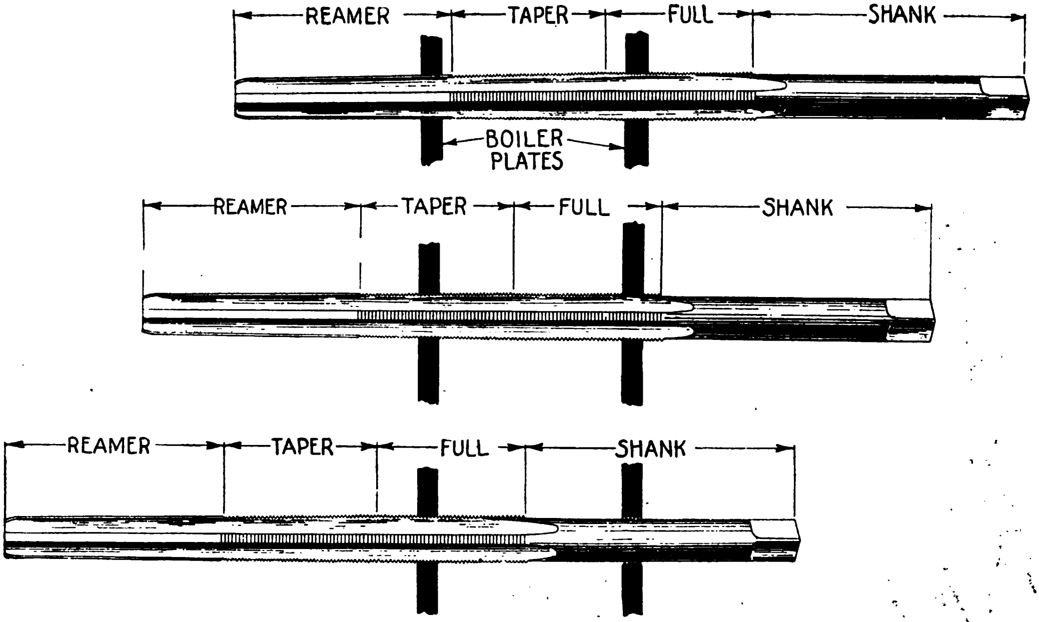
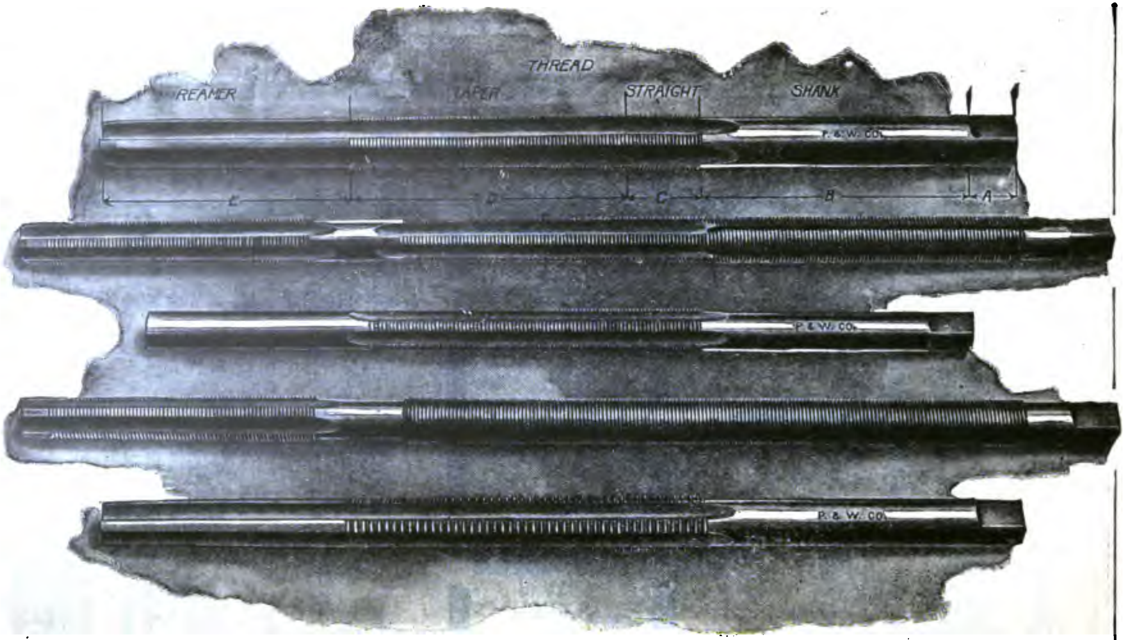
*NOTE.—The author objects to the use of the term ***brace*** because by definition a brace is a rigid piece, as of timber, to hold something, as parts of a frame in place, expecially 1, a framed diagonal piece in an angle, 2, a strut, and 3, lateral support acting in compression. The general conception of a brace is that it is a ***stiff member designed to resist both tension and compression.*** Accordingly, the author uses the term stay rather than brace.



FIGS. 3,907 to 3,909.—Stay bolt tap, showing method of using and illustrating how both plates are tapped in one operation so that the bolt will thread into both plates without interference.

That is an independent member is attached to a single surface and a connecting member joins two surfaces in which the pressure is acting in opposite or oblique directions.



FIGS. 3,910 to 3,914.—Pratt and Whitney stay bolt taps, illustrating different types.

Ques. How are boiler plates tapped so that a threaded bolt or stay will properly screw into both plates without stripping the threads?

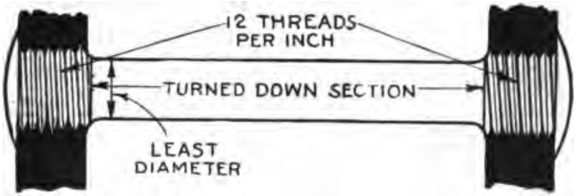
Ans. By the use of a long or stay bolt tap which threads both plates in one operation.

Ques. What thread is used for stay bolt taps?

Ans. All sizes of stay bolt taps have 12 threads to the inch, the approved form being the U. S. standard, though the "V" thread is sometimes used.

Ques. What diameter of a screwed stay is taken in calculating its strength?

Ans. The *least* diameter.



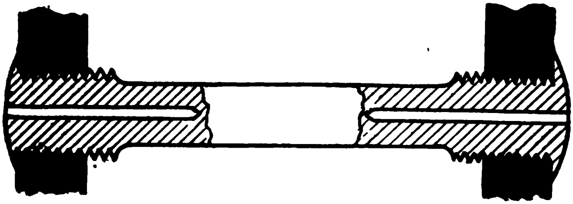


FIG. 3,915.—Riveted screw stay or so-called stay bolt. The standard sizes vary from ¾ to 1½ inches in diameter, and all have twelve threads per inch.

FIG. 3,916.—Hollow or drilled riveted screw stay.

For a continuous thread this is at the bottom of the thread, and at the middle section of turned stays.

Riveted Stays.—The usual form of riveted stay used for carrying the pressure on the sides of the fire box in vertical and locomotive boilers consists of a rod threaded at the ends and turned down along the middle section to a diameter slightly less than that of the root of the threads as shown in fig. 3,915.

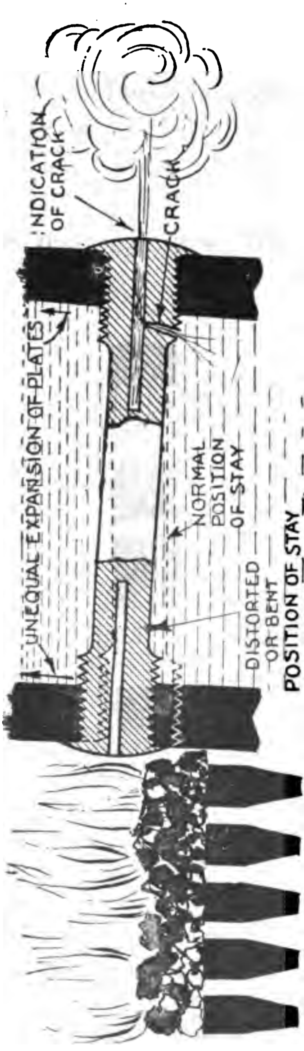


FIG. 3,917.—**Why screwed stays sometimes break.** The inner plate being exposed to the intense heat of the furnace expands more than the other one, hence a see-saw movement is set up with changes in temperatures. This continued bending action tends to crystallize the metal in time and cause it to crack. ***By drilling holes*** as shown, an extensive crack will be indicated by a leak or blow through the hole—***provided the hole has not*** *become closed by dirt and corrosion*. In the figure the dotted lines show normal or straight position of the stay, and the sectional view the bent position.

The approved form of riveted stay is shown in fig. 3,916. In this stay a 3/16 in. hole is drilled in each end as shown, extending ½ inch or more beyond the inside of the plate.

Ques. What is the object of drilling holes in the ends of screwed stays?

Ans. To show by a leak through the drilled holes where the stay has broken, as in fig. 3,917.

The break is most likely to occur near the plate and inspection in parts of boilers which must be stayed in this manner is in most cases impossible. Sometimes the drilled hole extends the length of the stay.

Ques. Why do screwed stays sometimes break?

Ans. Owing to unequal expansion between the outer and inner plates, the stays are bent back and forth each time this occurs, as shown in figs. 3,917.

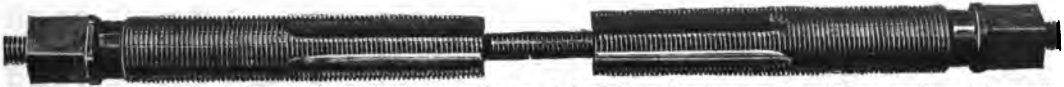


FIG. 3,918.—Pratt and Whitney spindle stay-bolt taps with threaded spindle. The taps are threaded externally and internally in a certain definite relationship so that continuity of lead from one tap to the other is positively maintained regardless of the distance between the taps. This construction insures the tapping of a continuous thread in the two boiler sheets where the stay bolt is to be located. The distance between the sheets may be anything within the limits of the spindle.

Ques. Where does the break occur?

Ans. Usually close to the outer sheet, because the inner sheet is generally thinner than the outer sheet, and therefore holds the end of the stay less rigidly.

Ques. What precaution should be taken with drilled stays?

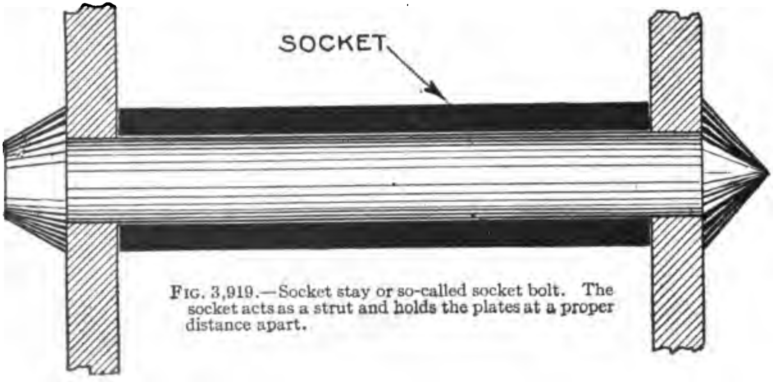


FIG. 3,919.—Socket stay or so-called socket bolt. The socket acts as a strut and holds the plates at a proper distance apart.

Ans. The holes should not be allowed to become closed by corrosion.

Socket Stays.—This type of so called stay bolt consists of a rod and socket. The socket is placed between the plates to be stayed and the rod passed through the plates and socket and riveted in place as shown in fig. 3,919.

Stay Rods or Through Stays.—These are used chiefly in marine shell boilers of the Scotch and Clyde types. These boilers being short and of large diameter, the considerable amount of flat surface in the heads not reinforced by the tubes is conveniently stayed with through stays without rendering the interior inaccessible. These stays are usually plain rods 1¼ to 2½ inches in diameter. The ends are fastened to the plates by nuts and washers as shown in figs. 3,920. The large washers are used to secure a larger heating surface.

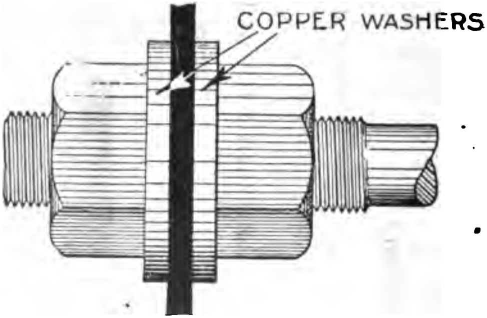


FIG. 3,920.—**Stay-rod or through-stay, especially adapted to short boilers of large diameter. The most common and simple form is a plain rod threaded at the ends. The rod passes through the steam space and the ends are fastened to the heads. The length is adjusted in various ways, the simplest being by nut and washers as here shown. The copper washers prevent abrasion of the plates by the nuts and act as packing in securing a tight joint. In place of the nuts the rod is sometimes bolted to angle irons which are riveted to the heads. In this case, turn buckles are used for adjusting the length.**

These stays being in the steam space should be at least 14 inches apart so that a man can pass between them. The threads at the ends may be cut on the plain rod or the ends may be forged larger and the threads cut on the enlarged part.

Stay Tubes.—Although the holding power of the ordinary tubes expanded into the heads is considerable and in most cases is sufficient for the sheet area covered, sometimes a few stay tubes are inserted, especially where the tube pitch is large.

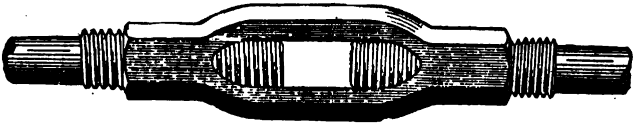
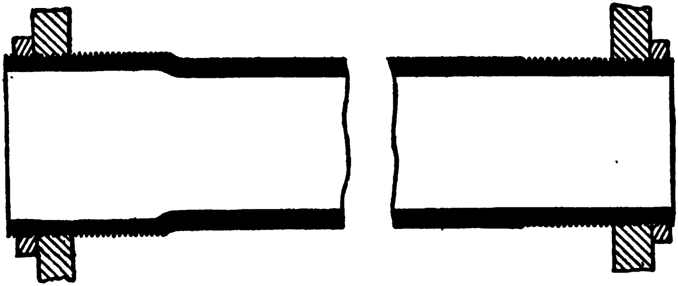


Fig. 3,921.—Turnbuckle used for adjusting the length of stay rods or through stays when the latter are bolted to internal angle irons instead of passing through the shell as in fig. 3,920.

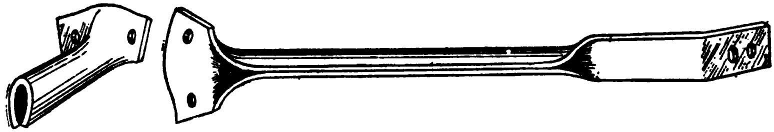
These tubes are of the same outside diameter as the ordinary tubes, but are thicker, being usually $\frac{1}{5}$-inch thick, and are provided with threads on the ends.

Frequently the threads are cut at both ends; both tube plates are tapped and the tubes screwed in. When both ends are threaded one end must be smaller than the other so that it may be slipped through the hole, as shown in figs. 3,922 and 3,923. The back end is beaded over or nutted and the front end fastened with shallow nuts. Sometimes two nuts are placed on the front end; one inside and one outside of the boiler plate.



Figs. 3,922 and 3,923.—Stay tube ends; fig. 3,922 upset end, fig. 3,923 plain end. It must be evident that where both ends are threaded one end must be of larger diameter than the other to allow inserting the tube.

Stay tubes are not used now as extensively as they were formerly. They were very common at a time when the holding power of expanded tubes had been experimented on but little. It is now apparent from numerous tests that the holding power of expanded tubes is more than is necessary to support the pressure coming on the spaces between the tubes of an ordinary tube sheet.



Figs. 3,924 and 3,925.—Luken's diagonal stay bent to form from a flat steel plate.

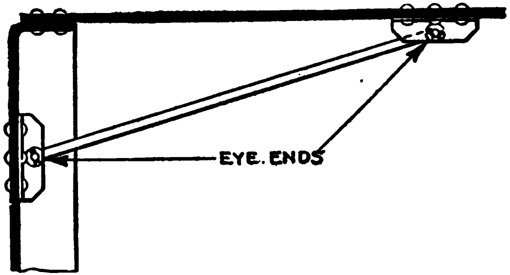


Fig. 3,926.—Diagonal stay with eye ends. It is attached to the boiler angle irons and pins.

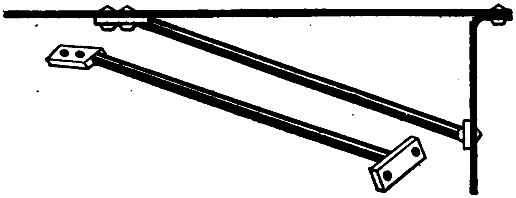


Fig. 3,927 and 3,928.—Diagonal stay with forged ends.

A.S.M.E. Boiler Code.—Stay Tubes.

232. When stay tubes are used in multi-tubular boilers to give support to the tube plates, the sectional area of such stay tubes may be determined as follows:

$$\text{Total section of stay tubes, square inches} = \frac{(A - a)\ P}{T}$$

where

A = area of that portion of the tube plate containing the tubes, sq. in.
a = aggregate area of holes in the tube plate, sq. in.
P = maximum allowable working pressure, pounds per sq. in.
T = working tensile stress allowed in the tubes not to exceed 7,000 lbs. per sq. in.

Gusset Stays.—The flat ends of cylindrical boilers (especially marine boilers) are stayed to the round portions of triangular plates of iron called gusset stays. These are simply pieces of plate iron secured to the boiler front or back, near the top or bottom, by means of two pieces of angle iron, then carried to the shell plating, and again secured by other pieces of angle bar, as shown in fig. 3,929.

Sometimes only one angle iron is used at each end, the plate itself being flanged to form the other side of the T.

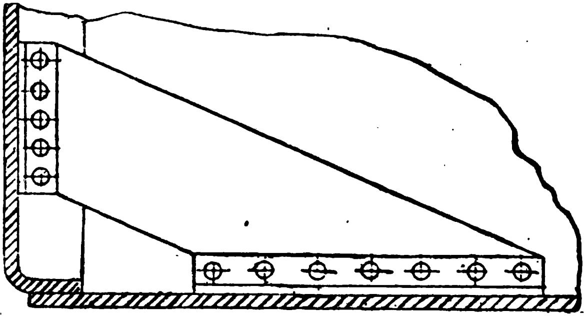


FIG. 3,929.—Gusset stay consisting of a flat piece attached diagonally to the shell and head by angle irons. Because of the character of the stress coming on a gusset stay it should be proportioned for a larger factor of safety than for ordinary diagonal stays.

A.S.M.E. Boiler Code.—Stay Tubes.—Continued.

T = working tensile stress allowed in the tubes, not to exceed 7,000 pounds per square inch

233 The pitch of stay tubes shall conform to the formula given in par. 199, using the values of *C* as given in Table 6.

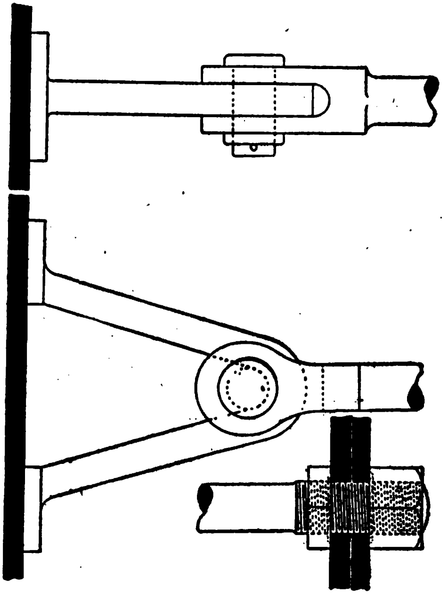
Table 6. Values of *C* for Determining Pitch of Stay Tubes.

Pitch of Stay Tubes in the Bounding Rows	When tubes have no Nuts Outside of Plates	When tubes are Fitted with Nuts Outside of Plates
Where there are two plain tubes between each stay tube	120	130
Where there is one plain tube between each stay tube...	140	150
Where every tube in the bounding rows is a stay tube and each alternate tube has a nut....................	....	170

Ques. How is the stress distributed in a Gusset stay?

Ans. The tension is not uniform, but is greater near one edge.

Palm Stays.—These are often used in the same position as a



FIGS. 3,930 and 3,931.—Crow-foot stay, consisting of a rod with forked end, attached by a pin to a V-shaped end with palms or so-called crow foot, the palms of which are riveted to the flat plate to be stayed.

***A.S.M.E. Boiler Code.**—Stay Tubes.—Continued.*

When the ends of tubes are not shielded from the action of flame or radiant heat, the values of C shall be reduced 20 per cent. The tubes shall project about ¼ inch at each end and be slightly flared. Stay tubes when threaded shall not be less than 3/16 inch thick at bottom of thread; nuts on stay tubes are not advised. For a nest of tubes C shall be taken as 140 and S as the mean pitch of stay tubes. For spaces between nests of tubes S shall be taken as the horizontal distance from center to center of the bounding rows of tubes and C as given in Table 6.

***U.S. Marine Rules.**—Diagonal and Gusset Stays.*

II—16. Multiply the area of a direct stay required to support the surface by the slant or diagonal length of the stay; divide this product by the length of a line drawn at right angles to surface supported to center of palm of diagonal stay. The quotient shall be the required area of the diagonal stay.

Gusset stay; that is, from the back or front end of the boiler to the shell plates; they are sometimes used to stay the curved tops of combustion chambers.

As shown in fig. 3,932, the stay consists of a round rod having forged on one end a plate or "palm" and a thread and nut connection at the other end.

Crow Foot Stays.—These are virtually double palm stays, two palms being connected together into a so-called crow foot, which is attached by a bolt to the forked end of a long bar.

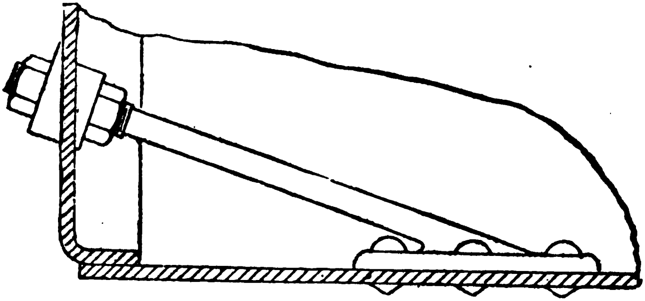
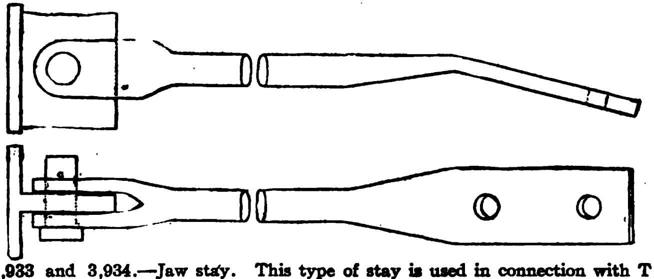


Fig. 3,932.—Palm stay, so-called because it has a palm-like plate forged at the end. Since the threaded end passes through the head obliquely, two diagonally cut washers are used as connectors between the nuts and plate.



Figs. 3,933 and 3,934.—Jaw stay. This type of stay is used in connection with T irons, riveted to the head.

This type is suited for long stays as it gives convenience for removal and repair of the long bolts without disturbing the crowfoot.

Jaw Stays.—This type of stay is shown in figs. 3,933 and 3,934 and consists of a round bar having jaws forged at one end and a flat plate at the other inclined at the proper angle for riveting to the boiler shell. The jaw end is attached by a pin to a T iron which is riveted to the head.

Steel Angle Stays.—When the shell of a boiler does not exceed 36 inches in diameter and is designed for a pressure of not over 100 pounds, the segment of heads above the tubes ***may*** be stayed by steel angles as shown in figs. 3,935 and 3,936.

The following table from the ***A.S.M.E. Boiler Code*** gives the approved dimensions for steel angle stays.

Table 5. Sizes of Angles Required for Staying Segments of Head

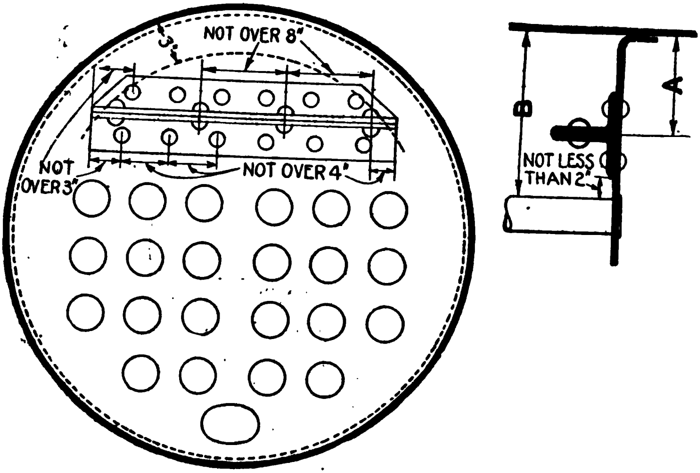
With the short legs of the angles attached to the head of the boiler

Height of segment, dimension ***B*** in Fig. 3,936	30-Inch Boiler			34-Inch Boiler			36-Inch Boiler			Dimension ***A*** in Fig. 3,936
	Angle 32× ½ In. Thickness, In.	Angle 3½×3 In. Thickness, In.	Angle 4×3 In. Thickness, In.	Angle 3½×3 In. Thickness, In.	Angle 4×3 In. Thickness, In.	Angle 5×3 In. Thickness, In.	Angle 4×3 In. Thickness, In.	Angle 5×3 In. Thickness, In.	Angle 6×3½ In. Thickness, In.	
10	3/8	5/16	5/16	—	—	—	—	—	—	6½
11	7/16	3/8	5/16	7/16	5/16	5/16	—	—	—	7
12	9/16	7/16	3/8	1/2	7/16	5/16	7/16	5/16	—	7½
13	—	9/16	7/16	11/16	1/2	5/16	9/16	3/8	—	8
14	—	—	1/2	—	5/8	3/8	5/8	7/16	3/8	8½
15	—	—	—	—	—	1/2	3/4	1/2	3/8	9
16	—	—	—	—	—	—	—	5/8	7/16	9½

Crown or Roof Bars.—For supporting the flat tops of fire boxes and combustion chambers, especially in locomotive and marine boilers a bridge or girder form of stay is often used. These bars extend across the flat surfaces and the ends rest on the side plates.

Bolts properly spaced connect the flat surface to the bar. The latter may be a solid bar or may be made up of two plates welded together at the ends and having a depth of about 4 to 6 inches and proper thickness to support the load coming on it.

Either bolts or rivets may be used to keep the plates which form the girder from spreading.



FIGS. 3,935 and 3,936.—Staying of head in tubular boiler with steel angles. The approved dimensions of these angles is given in the accompanying table from the A. S. M. E. Boiler Code. The legs attached to the heads may vary in depth ½ inch above or below the dimensions specified in the table. When this form of bracing is to be placed on a boiler, the diameter of which is intermediate to or below the diameters given in Table 5, the tabular values for the next higher diameter shall govern. Rivets of the same diameter as used in the longitudinal seams of the boiler shall be used to attach the angles to the head and to connect the outstanding legs. The rivets attaching angles to heads shall be spaced not over 4 inches apart. The centers of the end rivets shall be not over 3 inches from the ends of the angle. The rivets through the outstanding legs shall be spaced not over 8 inches apart; the centers of the end rivets shall be not more than 4 inches from the ends of the angles. The ends of the angles shall be considered those of the outstanding legs and the lengths shall be such that their ends overlap a circle 3 inches inside the inner surface of the shell as shown. The distance from the center of the angles to the shell of the boiler, marked **A**, shall not exceed the values given in the table, but in no case shall the leg attached to the head on the lower angle come closer than 2 inches to the top of the tubes. When the segments are beyond the range of the table the heads shall be braced or stayed in accordance with the requirements in these rules.

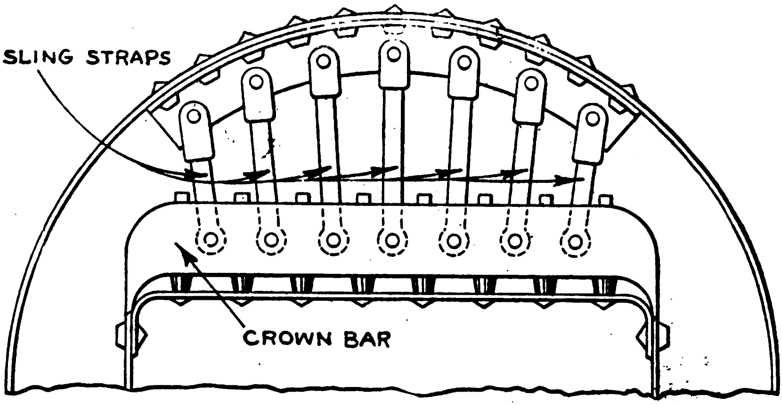
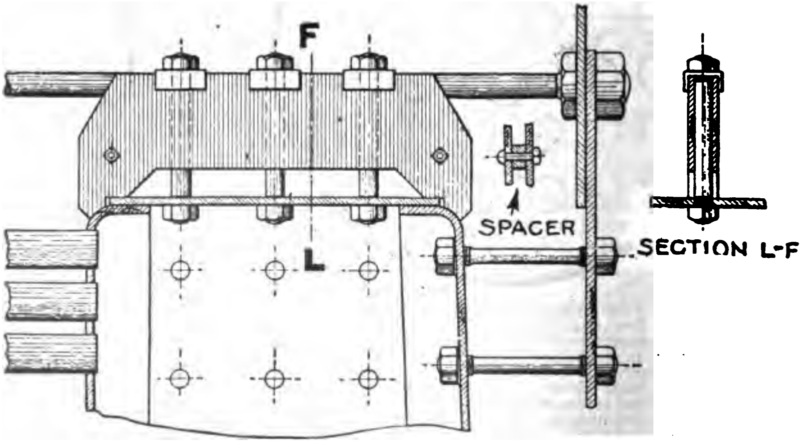


FIG. 3,937.—Detail of crown bar ***reinforced by sling straps.*** The sling stays are connected to the girder and to an angle iron or T iron, which is riveted to the shell. The angle iron stiffens the shell. In design, the crown bar should be strong enough to support the crown sheet independent of the sling straps.



FIGS. 3,938 to 3,940.—Details of crown bar construction supported by ***side plates.*** The bar is usually made up of bar plates having a depth of from 4 to 6 inches and a thickness of ⅝ to ¾ inches. If ⅞-inch stays be used, the distance between the plates is usually 1 inch. The plates are forged so that they take a bearing by means of feet on the edges of the side plates and support the furnace top by bolts which pass between the two strips and have a nut resting on a washer which spans the strips. The ends of the bars which rest upon the side plates should be carefully fitted to make a good bearing, and the area should be sufficient to prevent crushing. The distance between the crown sheet and the guides should be at least 1½ inches to insure good circulation and facilitate cleaning.

Radial Stays.—These are used chiefly in locomotive boilers, in which the fire box crown sheet is arched. The stays are arranged *radially* to the curvative of the two plates, which they connect, as shown in fig. 3,941.

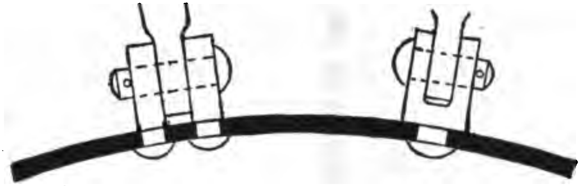


Fig. 3,941.—Detail of radial stays as connected to a curved or arched crown sheet.

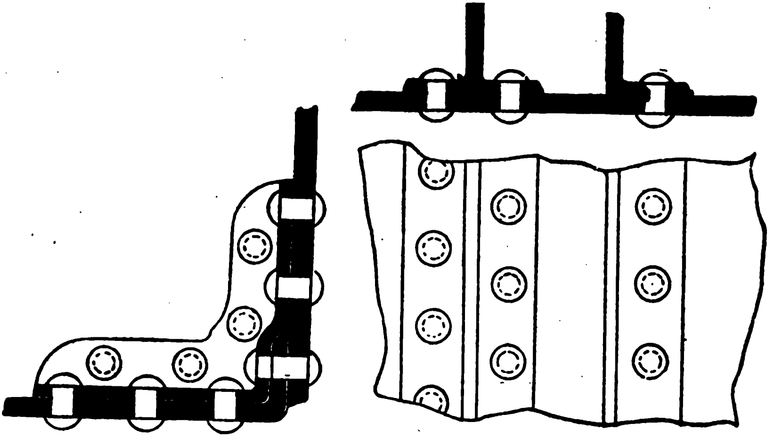


Fig. 3,942 to 3,944.—Details of corner angles or T braces.

***A. S. M. E. Boiler Code.**—Braced and stayed surfaces.*

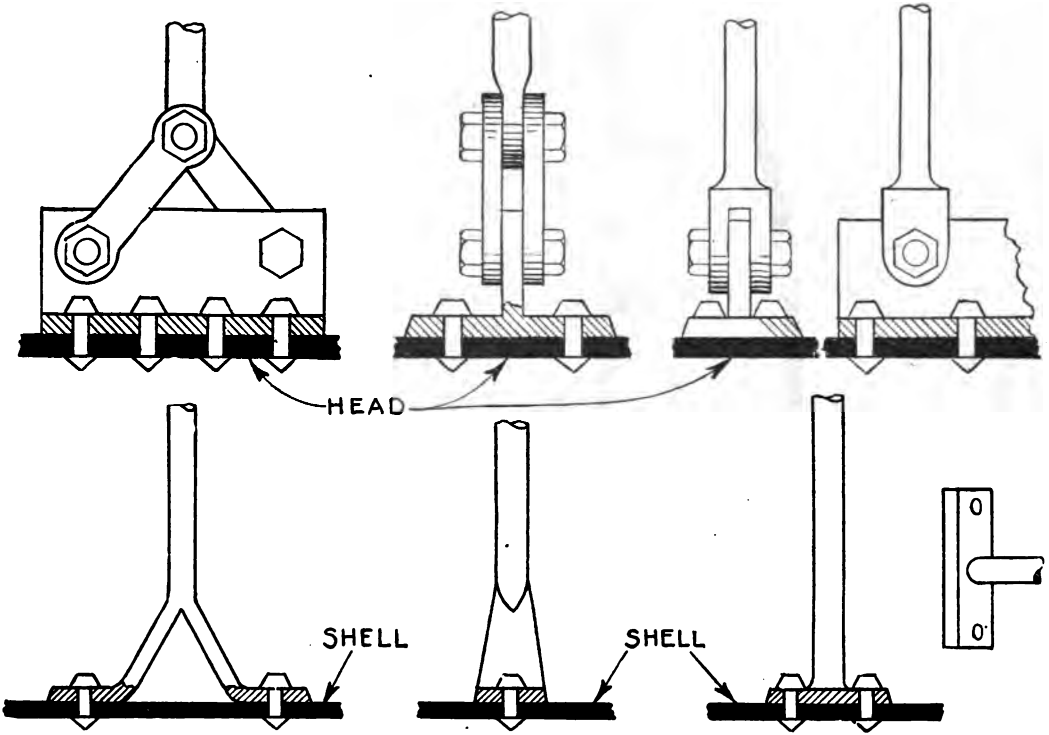
418. The allowable loads based on the net cross sectional areas of stay bolts with V threads, are computed from the following formulae. The use of Whitworth threads with other pitches is permissible. The formula for the diameter of a stay bolt at the bottom of a V thread is:

$$D—(P\times1.732)\ \mathrm{N}d$$

D Ndiameter of stay bolt over the threads, in.
P ×pitch of threads, in.
d Ndiameter of stay bolt at bottom of threads, in.
1.732 =a constant

Where U. S. threads are used, the formula becomes:

$$D—(P\times1.732\times.75)\ \mathrm{N}d$$



FIGS. 3,945 to 3,951.—***Methods of fastening stays.***—Figs. 3,945 to 3,947, head fastenings; figs. 3,948 to 3,951, shell fastenings.

***A. S. M. E. Boiler Code**—Stay Bolts.*

200 The ends of screwed staybolts shall be riveted over or upset by equivalent process. The outside ends of such staybolts shall be drilled with a hole at least $\frac{3}{16}$ inch diameter to a depth extending ½ inch beyond the inside of the plates, except on boilers having a grate area not exceeding 15 square feet, where the drilling of the staybolts is optional.

201 When channel irons or other members are securely riveted to the boiler heads for attaching through stays the transverse stress on such members shall not exceed 12,500 pounds per square inch. In computing the stress, the section modulus of the member shall be used without addition for the strength of the plate. The spacing of the rivets over the supported surface shall be in conformity with that specified for staybolts.

202 The ends of stays fitted with nuts shall not be exposed to the direct radiant heat of the fire.

203 The maximum spacing between centers of rivets attaching the crowfeet of braces to the braced surface, shall be determined by the formula in par. 199, using 135 for value of *C*.

The maximum spacing between the inner surface of the shell and lines parallel to the surface of the shell passing through the centers of the rivets attaching the crowfeet of braces to the head, shall be determined by the formula in par. 199, using 160 for the value of *C*.

Table 3. Maximum Allowable Pitch, in Inches, of Screwed Staybolts, Ends Riveted Over

Pressure Pounds per Square Inch	Thickness of Plate, Inches						
	$\frac{5}{16}$	⅜	$\frac{7}{16}$	½	$\frac{9}{16}$	⅝	$\frac{11}{16}$
	Maximum Pitch of Staybolts, Inches						
100	5¼	6⅜	7⅜	....	....	....	....
110	5	6	7	8⅜	....	....	....
120	4¾	5¾	6¾	8	....	....	....
125	4¾	5⅝	6⅝	7¾	....	....	....
130	4⅝	5½	6½	7⅝	....	....	....
140	4½	5⅜	6¼	7⅜	8⅜	....	....
150	4¼	5⅛	6	7⅛	8	....	....
160	4⅛	5	5⅞	6⅞	7¾	....	....
170	4	4⅞	5⅝	6¾	7½	8⅜	....
180	....	4¾	5½	6½	7⅜	8⅛	....
190	....	4⅝	5⅜	6⅜	7⅛	7⅞	....
200	....	4½	5¼	6⅛	7	7¾	8½
225	....	4¼	4⅞	5⅞	6½	7¼	8
250	....	4	4⅝	5½	6¼	6⅞	7⅝
300	....	....	4¼	5	5⅝	6¼	7

204 The formula in par. 199 was used in computing Table 3. Where values for screwed stays with ends riveted over are required for conditions not given in Table 3, they may be computed from the formula and used, provided the pitch does not exceed 8½ inches.

A.S.M.E. Boiler Code.—Stay Bolts.—Continued.

205 The distance from the edge of a staybolt hole to a straight line tangent to the edges of the rivet holes may be substituted for p for staybolts adjacent to the riveted edges bounding a stayed surface. When the edge of a stayed plate is flanged, p shall be measured from the inner surface of the flange, at about the line of rivets to the edge of the staybolts or to the projected edge of the staybolts.

206 The distance between the edges of the staybolt holes may be substituted for p for staybolts adjacent to a furnace door or other boiler fitting, tube hole, hand hole or other opening.

207 In water leg boilers, the staybolts may be spaced at greater distances between the rows than indicated in Table 3, provided the portions of the sheet which come between the rows of staybolts have the proper transverse strength to give a factor of safety of at least 5 at the maximum allowable working pressure.

208 The diameter of a screw stay shall be taken at the bottom of the thread, provided this is the least diameter.

209 The least cross-sectional area of a stay shall be taken in calculating the allowable stress, except that when the stays are welded and have a larger cross-sectional area at the weld than at some other point, in which case the strength at the weld shall be computed as well as in the solid part and the lower value used.

210 Holes for screw stays shall be drilled full size or punched not to exceed $\frac{1}{4}$ inch less than full diameter of the hole for plates over $\frac{5}{16}$ inch in thickness, and $\frac{1}{8}$ inch less than the full diameter of the hole for plates not exceeding $\frac{5}{16}$ inch in thickness, and then drilled or reamed to the full diameter. The holes shall be tapped fair and true, with a full thread.

211 The ends of steel stays upset for threading, shall be thoroughly annealed.

212 An internal cylindrical furnace which requires staying shall be stayed as a flat surface as indicated in Table 3.

213 *Staying Segments of Heads.* A segment of a head shall be stayed by head to head, through, diagonal, crowfoot or gusset stays, except that a horizontal return tubular boiler, may be stayed as provided in Pars. 225 to 229 (see Boiler Code.)

214 *Areas of Segments of Heads to be Stayed.* The area of a segment of a head to be stayed shall be the area enclosed by lines drawn 3 inches from the shell and 2 inches from the tubes, as shown in figs. 3,904 and 3,905.

215 In water tube boilers, the tubes of which are connected to drum heads, the area to be stayed shall be taken as the total area of the head less a 5 inch annular ring, measured from the inner circumference of the drum shell.

When such drum heads are 30 inches or less in diameter and the tube plate is stiffened by flanged ribs or gussets, no stays need by used if a hydrostatic test to destruction of a boiler or unit section built in accordance with the construction, shows that the factor of safety is at least 5.

216 In a fire tube boiler, stays shall be used in the tube sheets if the distances between the edges of the tube holes exceed the maximum pitch of staybolts given in Table 3. That part of the tube sheet which comes between the tubes and the shell, need not be stayed when the distance from the inside of the shell to the outer surface of the tubes does not exceed that given by the formula in par. 199, (page 2,201) using 160 for the value of C.

217 The net area to be stayed in a segment of a head may be determined by the following formula:

$$\frac{4\ (H-5)^2}{3}\times\sqrt{\frac{2\ (R-3)}{(H-5)}}-.608=\text{area to be stayed, sq. in.}$$

where

H = distance from tubes to shell, in.
R = radius of boiler head, in.

218 When the portion of the head below the tubes in a horizontal return tubular boiler is provided with a manhole opening, the flange of which is formed from the solid plate and turned inward to a depth of not less than three times the thickness of the head, measured from the outside, the area to be stayed as indicated in fig. 3,905, may be reduced by 100 sq. in. The surface around the manhole shall be supported by through stays with nuts inside and outside at the front head.

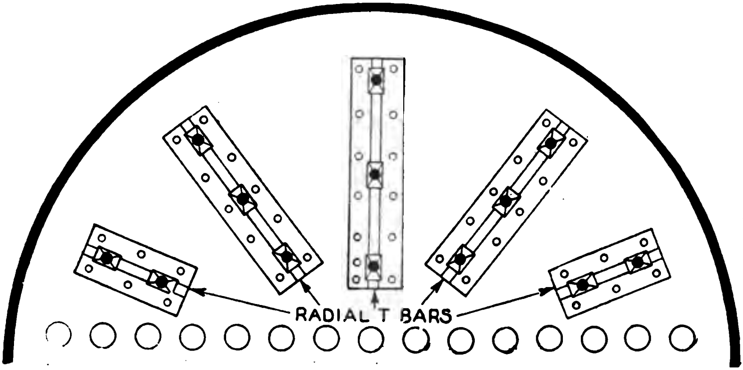


Fig. 3,952.—Radial T bars for fastening stays to heads.

***Boiler Code.**—Stay Bolts—Continued.*

Table 4. Maximum Allowable Stresses for Stays and Staybolts

Description of stays	Stresses, pounds per square inch	
	For lengths between supports not exceeding 120 diameters	For lengths between supports exceeding 120 diameters
a Unwelded stays less than twenty diameters long screwed through plates with ends riveted over.... ..	7,500	....
b Unwelded stays and unwelded portions of welded stays, except as specified in line *a*................	9,500	8,500
c Welded portions of stays............	6,000	6,000

219 When stay rods are screwed through the sheets and riveted over, they shall be supported at intervals not exceeding 6 feet. In boilers without manholes, stay rods over 6 feet in length may be screwed through the sheets and fitted with nuts and washers on the outside.

220 The maximum allowable stress per square inch net cross sectional area of stays and staybolts shall be as given in Table 4.

The length of the stay between supports shall be measured from the inner faces of the stayed plates. The stresses are based on tension only. For computing stresses in diagonal stays, see pars. 221 and 222.

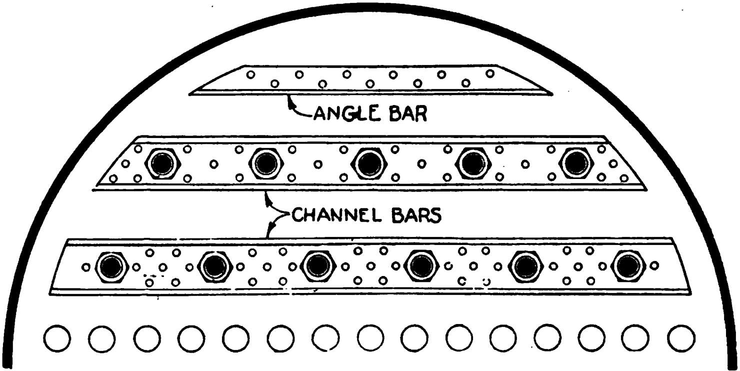


FIG. 3,953.—Angle and channel bars for through stay connections.

A.S.M.E. Boiler Code—Stresses in Diagonal and Gusset Stays

221 Multiply the area of a direct stay required to support the surface by the slant or diagonal length of the stay; divide this product by the length of a line drawn at right angles to surface supported to center of palm of diagonal stay. The quotient will be the required area of the diagonal stay.

$$A = \frac{a \times L}{l}$$

where

A = sectional area of diagonal stay, sq. in.
a = sectional area of direct stay, sq. in.
L = length of diagonal stay, in.
l = length of line drawn at right angles to boiler head or surface supported to center of palm of diagonal stay, in.

Given diameter of direct stay = 1 in., $a = 0.7854$, $L = 60$ in., $l = 48$ inches; substituting and solving:

$$A = \frac{.7854 \times 60}{48} = .981 \text{ sectional area, sq. in.}$$

Diameter = 1.11 inches = $1\frac{1}{8}$ in.

222 For staying segments of tube sheets such as horizontal return tubular boilers, where L is not more than 1.15 times l for any brace, the stays may be calculated as direct stays, allowing 90 per cent. of the stress given in Table 4 (page 2,221).

A.S.M.E. Boiler Code.—Diameter of pins and area of rivets in brace.

223 The sectional area of pins to resist double shear and bending when secured in crowfoot, sling, and similar stays shall be at least equal to three-fourths of the required cross-sectional area of the brace. The combined cross section of the eye at the sides of the pin shall be at least 25 per cent. greater than the required cross-sectional area of the brace.

The cross-sectional area of the rivets attaching a brace to the shell or head shall be not less than one and one quarter times the required sectional area of the brace. Each branch of a crowfoot shall be designed to carry two-thirds of the total load on the brace. The net sectional areas through the sides of the crowfeet, tee irons or similar fastenings at the rivet holes shall

A.S.M.E. Boiler Code.—Diameter of pins and area of rivets in braces.—Continued.

be at least equal to the required rivet section. All rivet holes shall be drilled and burrs removed, and the pins shall be made a neat fit.

224 Gusset stays when constructed of triangular right-angled web plates secured to single or double angle bars along the two sides at right angles shall have a cross-sectional area (in a plane at right angles to the longest side and passing through the intersection of the two shorter sides) not less than 10 per cent. greater than would be required for a diagonal stay to support the same surface, figured by the formula in par. 221, assuming the diagonal stay is at the same angle as the longest side of the gusset plate.

A.S.M.E. Boiler Code.—Crown bars and girder stays.

230 Crown bars and girder stays for tops of combustion chambers and back connections, or wherever used, shall be proportioned to conform to the following formula:

$$\text{Maximum allowable working pressure} = \frac{C \times d^2 \times T}{(W - P) \times D \times W}$$

where

W = extreme distance between supports, in.
P = pitch of supporting bolts, in.
D = distance between girders from center to center, in.
d = depth of girder, in.
T = thickness of girder, in.
C = 7,000 when the girder is fitted with one supporting bolt
C = 10,000 when the girder is fitted with two or three supporting bolts
C = 11,000 when the girder is fitted with four or five supporting bolts
C = 11,500 when the girder is fitted with six or seven supporting bolts
C = 12,000 when the girder is fitted with eight or more supporting bolts

Example: Given $W = 34$ in., $P = 7.5$ in., $D = 7.75$ in., $d = 7.5$ in., $T = 2$ in.; three stays per girder, $C = 10{,}000$; then substituting in formula:

$$\text{Maximum allowable working pressure} = \frac{10{,}000 \times 7.5 \times 7.5 \times 2}{(34 - 7.5) \times 7.75 \times 34} = 161.1 \text{ lb. per sq. in.}$$

U.S. Marine Rules.—Stays.

The maximum working pressure in pounds allowable per square inch of cross-sectional area for stays used in the construction of marine boilers where same are accurately fitted normal to supported surfaces and properly secured shall be ascertained by the following formula:

$$P = \frac{A \times C}{a}$$

Where P = working pressure in pounds.
A = least cross-sectional area of stay in inches.
a = area of surface supported by one stay in inches.
C = a constant.
C = 9,000 for tested steel stays 1 inch and upward in diameter when such stays are not forged or welded. The ends may be upset to a sufficient diameter to allow for the depth of the thread. The diameter shall be taken at the bottom of the thread, provided it is the least diameter of the stay. All such stays after being upset shall be thoroughly annealed.
C = 8,000 for a tested Huston or similar type of brace, the cross-sectional area of which exceeds 5 square inches.
C = 7,000 for such tested braces when the cross-sectional area is not less than 1.227

***U.S. Marine Rules.**—Stays.—Continued*

and not more than 5 square inches, provided such braces are prepared at one heat from a solid piece of plate without welds.

$C = 7,500$ for wrought iron stays 1 inch and upward in diameter when made of the best quality of refined iron. The ends may be upset to allow for the depth of the thread. The diameter shall be taken at the bottom of the thread, provided it is the least diameter of the stay. Such stays may be welded.

Where $C = 6,000$ for welded crowfoot stays when made of best quality of refined wrought iron, and for all stays not otherwise provided for when made of the best quality of refined iron or steel without welds.

Example.—Required the working pressure of a stay 1 inch in diameter, pitched 6 inches by 6 inches center to center.

$$\text{Working pressure} = \frac{(1 \times 1 \times .7854) \times 6,000}{6 \times 6} = 130.9 \text{ pounds.}$$

Stay bolts and stays made of the best quality of refined wrought iron may be welded. The lengthening of steel stays by welding shall not be allowed.

***U.S. Marine Rules.**—Screw Stays.*

The diameter of a screw stay shall be taken at the bottom of the thread, provided it is the least diameter of the stay.

For all stays the least sectional area shall be taken in calculating the stress allowable.

All screw stay bolts shall be drilled at the ends with a three-sixteenths-inch hole to at least a depth of one-half inch beyond the inside surface of the sheet. Stays through laps or butt straps may be drilled with larger hole to a depth so that the inner end of said larger hole shall not be nearer than the thickness of the boiler plates from the inner surface of the boiler. Hollow-rolled screw stay bolts may be used.

Flexible stay bolts that are made with a ball in socket on one end, the socket screwed into the outside sheet and covered with a removable cap and bolt screwed into the inside sheet and riveted over, may be used for staying flat surfaces without being drilled with a telltale hole.

Such screw stay bolts, with or without sockets, may be used in the construction of marine boilers where fresh water is used for generating steam: *Provided, however,* That screw stay bolts of a greater length than 24 inches will not be allowed in any instance, unless the ends of said bolts are fitted with nuts. Water used from a surface condenser shall be deemed fresh water.

Holes for screw stays shall be tapped fair and true, and full thread.

The ends of stays which are upset to include the depth of thread shall be thoroughly annealed after being upset.

***U.S. Marine Rules.**—Pins and Rivets.*

The sectional area of pins to resist double shear and bending, accurately fitted and secured in crowfeet, sling, and similar stays, shall be at least equal to eight-tenths of the required sectional area of the brace. Breadth across each side and depth to crown of eye shall not be less than .35 of diameter of pin. In order to compensate for inaccurate distribution the forks shall be proportioned to support two-thirds of the load, thickness of forks to be not less than .66 of the diameter of pin.

The combined sectional area of rivets used in securing tee irons and crowfeet to shell, said rivets being in tension, shall be not less than the required sectional area of brace. To insure a well proportioned rivet point, rivets shall be of sufficient length to completely fill the rivet holes and form a head equal in strength to the body of the rivet. All rivet holes shall be drilled. Distance from center of rivet hole to edge of tee irons, crowfeet, and similar fastenings, shall be so proportioned that the net sectional areas through sides at rivet holes shall equal the required rivet section. Rivet holes shall be slightly countersunk in order to form a fillet at point and head.

Boiler Openings.—There are numerous openings into the water and steam space of the boiler which are necessary for proper operation and care. They may be divided into classes:

1. The major openings.

U.S. Marine Rules.—*Pins and rivets.—Continued.*

When sling stays are connected by pins to angles secured to shell, said angles shall be of sufficient depth to resist shear. Section to resist shear shall be of sufficient depth to resist shear. Section to resist shear shall be determined by the following formula:

$$A = D \times 2T$$

$$D = \frac{A}{2T}$$

Where A = sectional area of pin.
D = depth from edge of pinhole to end of leg.
2T = thickness of two angles.

Example.

Diameter of sling stay, 2 inches. Diameter of pin, 1.6 inches. Thickness of angle, seven-eighths of an inch. Required the depth from edge of pinhole to end of leg.

Substituting values and solving:

$$D = \frac{.7854 \times 1.6 \times 1.6}{2 \times .875} = 1.15 \text{ inches.}$$

Minimum diameter of rivets shall be found as follows:

$$\text{Minimum diameter} = \sqrt{\frac{\text{load}}{.7854 \times 12{,}000 \times N}}$$

where N equals number of rivets. Rivets shall be staggered in each leaf.

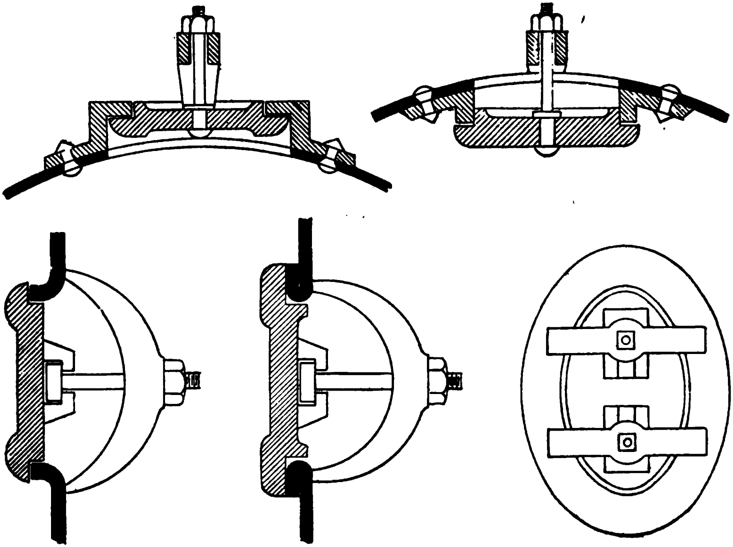
U.S. Marine Rules.—*Tests of Bars for Stays and Braces.*

All steel bars to be used as stays or braces in marine boilers and allowed a stress of 7,000, 8,000, or 9,000 pounds per square inch of section, tested by the United States assistant inspectors at the mills where the material is manufactured, shall be tested in the following manner: There shall be taken from each heat two pieces for tensile tests and two pieces for bending tests. The full-size bars within the capacity of the testing machine may be used for tensile tests. Where the full size of the bar is too large for the capacity of the testing machine, the bar may be reduced in size to meet such capacity. To facilitate and insure accurate tests, all bars for tensile and bending tests may be reduced in size. The minimum tensile strength of each test piece shall be not less than 58,000 pounds per square inch of section and each test piece that has been reduced in size shall show an elongation of at least 28 per cent. in 2 inches. Where the full size of the bar has been used for testing, the test piece shall show an elongation of at least 25 per cent. in 8 inches. When the tensile strength of the test piece is more than 63,000 pounds per square inch of section, each test piece that has been reduced in size shall show an elongation of at least 26 per cent. in 2 inches. Where the full size of the bar has been used for testing, each test piece shall show an elongation of at least 22 per cent. in 8 inches. The pieces for the bend test shall be bent cold to a curve, the inner radius of which is equal to one and one-half times the diameter of the bar without flaws or cracks. Should any such test bar fail in either the tensile or bending test, no bars from such heat shall be allowed to be used in the construction of any marine boiler. Where a heat of steel bars has been passed by an inspector, separate lots of bars from such heat may be furnished to different boiler manufacturers upon a certificate from the mill that the bars were made from such accepted heat.

a. Hand hole
b. Man hole

2. The minor openings.

- *a*. *Steam*
  - main outlet
  - outlet for safety valve
  - outlets for auxiliary steam
  - *outlet for injector*
- *b*. *Water*
  - outlets for gauge cocks
  - outlets for water gauge
  - outlet for blow off valve
  - outlet for scum cock
  - inlet for feed water



Figs, 3,954 to 3,958.—Hand hole and man hole construction.

Hand Holes and Man Holes.—These are placed in such position that accumulations of sediment can be removed and that tools can be inserted for cleaning boiler tubes and shell and so that entrance can be had for the examination and replacing of stays, braces, tubes and pipe connections. The man hole for a horizontal tubular boiler is usually placed in the top of the shell or, for large boilers, in the head above the water line. In water-tube boilers the man hole is placed in the end of the steam drum and for large sizes a manhole is placed in the end of the mud drum as well. For smaller sizes a large hand hole is used in the mud drum in place of the man hole.

In horizontal tubular boilers, the hand hole is placed in each head below the tubes and for vertical boilers hand holes are placed opposite the crown sheet and at the bottom of the water leg. The man hole is usually made 11×15 inches, the longer diameter being placed at right angles to the axis of the shell. The opening is made elliptical, and since the removal of the section of the shell reduces its strength, reinforcement must be used, either by flanging over the shell or by riveting on a collar around the opening.

The sectional area of the reinforcing rings should be not less than that of the plate removed measured on the line parallel to the axis of the shell.

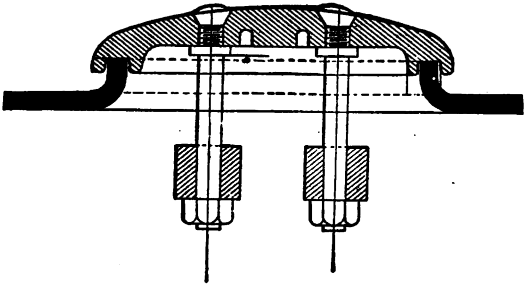


FIG. 3.959.—Eclipse man-hole construction.

Many builders of boilers use a special form of man hole head called the 'Eclipse." In this the strengthening of the shell is secured by flanging the boiler head around the opening and a steam tight joint is formed by using a tongue and groove joint, as shown in fig. 3,959.

The accompanying table shows the area of hand and man holes in square inches, and will be found useful in calculating the total pressure upon the hand and man hole plates.

A.S.M.E. Boiler Code.—Man holes.

258. An elliptical manhole opening shall be not less than 11 × 15 inches or 10 × 16 inches in size. A circular manhole opening shall be not less than 15 inches in diameter.

259. A manhole reinforcing ring when used, shall be of steel or wrought iron, and shall be at least as thick as the shell plate.

260. Manhole frames on shells or drums when used, shall have the proper curvature, and on boilers over 48 inches in diameter shall be riveted to the shell or drum with two rows of rivets, which may be pitched as shown on page 2,215. The strength of the rivets in shear on manhole frames and reinforcing rings shall be at least equal to the tensile strength of that part of the shell plate removed, on a line parallel to the axis of the shell, through the center of the manhole, or other opening.

Area of Hand Holes and Man Holes

Short diameter	Long diameter								
	6	8	10	12	12½	13	14	14½	15
	Area in square inches								
4	18.85	—	—	—	—	—	—	—	—
4½	21.2	—	—	—	—	—	—	—	—
5	23.56	31.41	—	—	—	—	—	—	—
5½	—	34.55	—	—	—	—	—	—	—
6	—	37.69	47.12	—	—	—	—	—	—
6½	—	40.84	51.04	61.62	—	—	—	—	—
7	—	43.98	54.97	65.97	68.72	71.47	—	—	—
7½	—	—	58.90	70.68	73.59	76.57	—	—	—
8	—	—	62.83	75.39	78.54	81.68	87.96	—	—
8½	—	—	66.75	80.13	83.64	86.78	93.46	97.23	—
9	—	—	—	84.82	88.36	91.89	99.06	102.49	—
9½	—	—	—	89.53	93.3	96.99	104.45	108.18	111.91
10	—	—	—	94.24	98.17	102.10	109.95	113.88	117.81
10½	—	—	—	—	103.08	107.20	115.45	119.61	123.70
11	—	—	—	—	—	112.31	120.95	125.27	129.59

A.S.M.E. Boiler Code.—Man holes.—Continued.

261. The proportions of manhole frames and other reinforcing rings to conform to the above specifications may be determined by the use of the following formulæ, which are based on the assumption that the rings shall have the same tensile strength per square inch of section as, and be of not less thickness than, the shell plate removed.

For a single-riveted ring: $W=\frac{l\times t_1}{2\times t}+d$

For a double-riveted ring: $W=\frac{l\times t_1}{2\times t}+2d$

For two single-riveted rings: $W=\frac{l\times t_1}{4\times t}+d$

For two double-riveted rings: $W=\frac{l\times t_1}{4\times t}+2d$

Where

W = least width of reinforcing ring, in.

Ques. How is the area of an elliptical hand or man hole plate calculated?

Ans. The area of an ellipse is equal to the product of its semi-axes×3.1416, or=product of its axes×.7854.

Ques. Why is only one or two bolts sufficient for securing a hand or man hold cover to the boiler?

Ans. Because the pressure of the steam does not come on the bolts but on the boiler plate, the bolts serving merely to hold the cover in place when there is no internal pressure on the boiler.

A.S.M.E.—Boiler Code.—Man holes.—Continued.

t_1 =thickness of shell plate, in.
d =diameter of rivet when driven, in.
t =thickness of reinforcing ring—not less than thickness of the shell plate, in.
T =tensile strength of the ring, pounds per sq. in. of section
a =net section of one side of the ring or rings, sq. in.
S =shearing strength of rivet, pounds per sq. in. of section (see par. 16, page 2,177.)
l =length of opening in shell in direction parallel to axis of shell, in.
N =number of rivets

To find the number of rivets for a single or double reinforcing ring:

$$N + = \frac{5.1 \times T \times a}{S \times d^2}$$

262. Man hole plates shall be of wrought steel or shall be steel castings.

263. The minimum width of bearing surface, for a gasket on a manhole opening shall be ½ inch. No gasket for use on a man hole or hand hole of any boiler shall have a thickness greater than ¼ inch.

264. A man hole shall be located in the front head, below the tubes, of a horizontal return tubular boiler 48 inches or over in diameter. Smaller boilers shall have either a man hole or a hand hole below the tubes. There shall be a man hole in the upper part of the shell or head of a fire-tube boiler over 40 inches in diameter, except a vertical fire-tube boiler, or except on internally fired boilers not over 48 inches in diameter. The man hole may be placed in the head of the dome. Smaller boilers shall have either a man hole or a hand hole above the tubes.

A.S.M.E. Boiler Code.—Washout Holes.

265. A traction, portable or stationary boiler of the locomotive type shall have not less than six hand holes, or washout plugs, located as follows: one in the rear head below the tubes; one in the front head at or about the line of the crown sheet; four in the lower part of the water leg; also, where possible, one near the throat sheet.

266. A vertical fire-tube boiler, except the boiler of a steam fire-engine, shall have not less than seven hand holes, located as follows: three in the shell at or about the line of the crown sheet; one in the shell at or about the line of the fusible plug when used; three in the shell at the lower part of the water leg. A vertical fire-tube boiler, submerged tube type, shall have two or more hand holes in the shell, in line with the upper tube sheet.

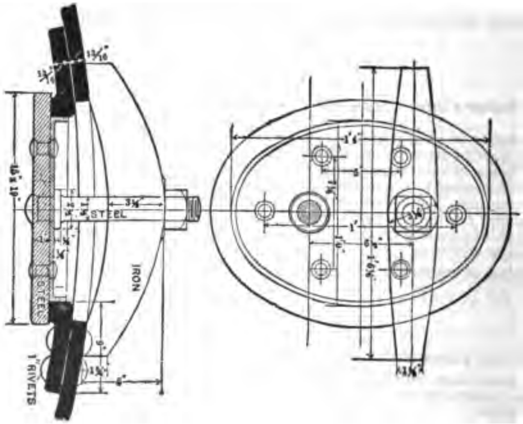
267. A vertical fire-tube boiler of a steam fire-engine shall have at least three brass washout plugs of not less than 1-inch iron pipe size, screwed into the shell and located as follows: one at or about the line of the crown sheet; two at the lower part of the water leg.

Ques. When a man hole is cut in a shell how is the shell reinforced?

Ans. By a forged steel ring fitted about the hole as shown in figs. 3,960 and 3,961.

Ques. How is a tight joint secured on a hand or man hole?

Ans. By means of a gasket.



FIGS. 3,960 and 3,961.—Man-hole and shell construction, showing reinforcing ring and other details.

U. S. Marine Rules.—Manholes, Handholes, and Holes for Pipe Connections.

4. All boilers built on and after August 1, 1914, shall have a manhole opening above the flues or tubes of not less than 10 by 16 inches, 11 by 15 inches, or of an equal area, in the clear, and shall have such other manhole openings in other parts of the boiler as may be required by local inspectors when considering blue prints or tracings submitted to them for approval, of sufficient dimensions to allow easy access to the interior of the boiler for the purpose of inspection and examination.

When holes exceeding 6 inches in diameter are cut in boilers for pipe connections, manhole and handhole plates, such holes shall be reinforced, either on the inside or outside of boiler, with reinforcing wrought-iron or steel rings, which shall be securely riveted or properly fastened to the boiler, such reinforcing material to be rings of sufficient width and thickness of material to fully compensate for the amount of material cut from such boilers, in flat surfaces; and where such opening is made in the circumferential plates of such boilers, the reinforcing

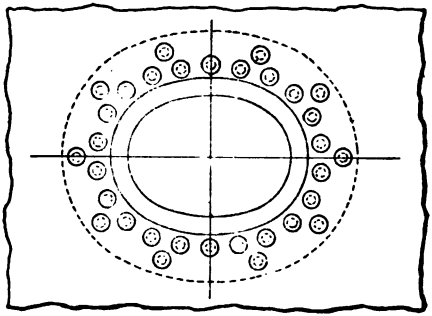


FIG. 3,962.—Method of riveting man-hole frames to shells or drums with two rows of rivets.

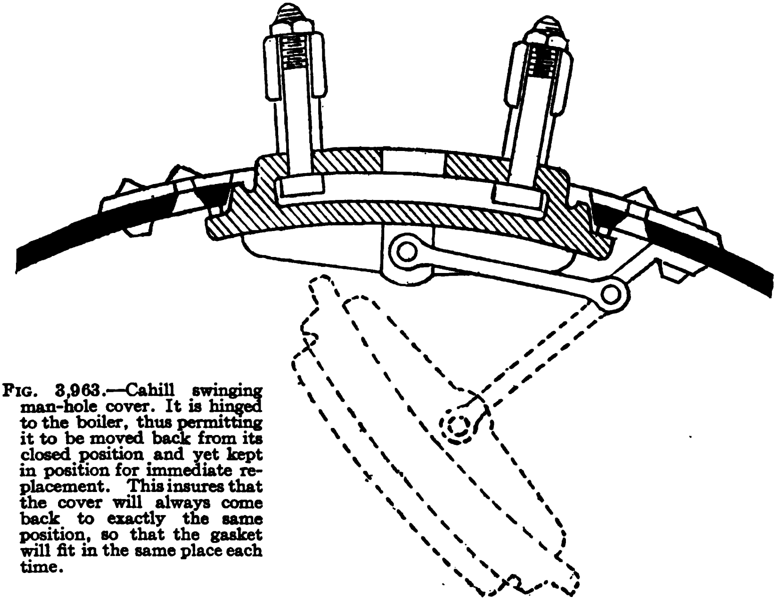


FIG. 3,963.—Cahill swinging man-hole cover. It is hinged to the boiler, thus permitting it to be moved back from its closed position and yet kept in position for immediate replacement. This insures that the cover will always come back to exactly the same position, so that the gasket will fit in the same place each time.

U.S. Marine Rules.—Man holes, hand holes and holes for pipe connections.—Continued

ring shall have a sectional area equal to at least one-half of the sectional area of the opening parallel with the longitudinal seams of such portion of the boiler. On boilers carrying 75 pounds or less steam pressure a cast-iron stop valve, properly flanged, may be used as a reinforcement to such opening. When holes are cut in any flat surface of such boilers and such holes are

Steam Domes.—The use of steam domes is practically a thing of the past except on locomotive and some special boilers.

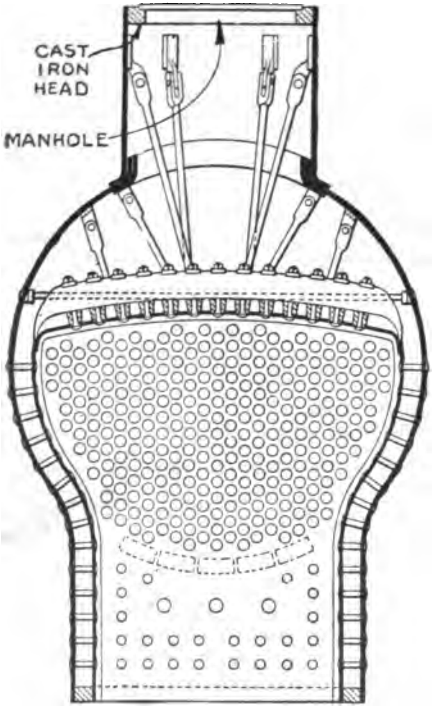


Fig. 3,964.—Steam dome with cast iron head arranged for man-hole on ocomotive boiler.

Formerly it was thought that nearly dry steam could not be obtained without the use of a dome, but it has since been found out that practically the same results can be obtained without a dome by means of a properly designed so called dry pipe, collecting the steam along the entire length of the boiler. This avoids the extra expense of a dome and the objection that it tends to weaken the shell.

Ques. What is necessary to obtain good results with either a steam dome or a dry pipe?

U. S. Marine Rules.—Manholes, handholes and holes for pipe connections.—Continued

flanged inwardly to a depth of not less than 1½ inches, measuring from the outer surface, the reinforcement rings may be dispensed with.

When reinforcing rings as described above are made of wrought iron or steel, the material shall not be required to be tested.

Seamless forged steel nozzles may be used for reinforcing holes cut in boilers when the amount of material in the flange of the saddle that is secured to the boiler is equal to the amount of material removed from the boiler.

No connection between shell of boiler and mud drum shall exceed 9 inches in diameter, and the flange of the mud-drum leg shall consist of an equal amount of material to that cut out of the shell of boiler. (Sec. 4418, R. S.)

Ans. There should be an adequate amount of liberating surface, and the boiler not operated beyond a reasonable overload capacity.

Ques. What size opening is cut in the shell to communicate with the dome?

Ans. Some makers place the upper man hole in the dome instead of the boiler head, while others make the opening just large enough to pass the steam at the proper velocity.

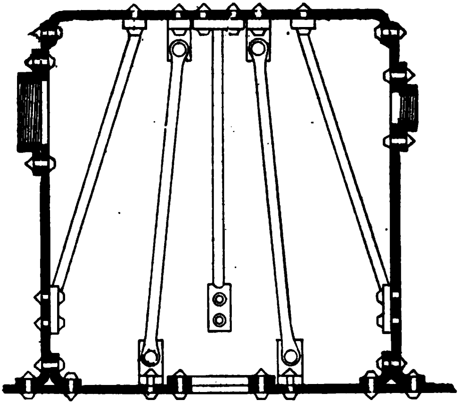


FIG. 3,965.—**Steam dome with diagonal bracing and having steam and drain opening in shell.**

For man hole construction the large opening is reinforced by flanging the shell into the dome, as in fig. 3,964, and sometimes further strengthened by riveting around it a heavy ring. Where the opening serves solely as a steam outlet small drain holes should be dulled at the lowest point on each side.

A.S.M.E. Boiler Code—Domes.

194 The longitudinal joint of a dome 24 in. or over in diameter shall be of butt and double-strap construction, and its flange shall be double riveted to the boiler shell when the maximum allowable working pressure exceeds 100 lb. per sq. in.

The longitudinal joint of a dome less than 24 in. in diameter may be of the lap type, and its flange may be single riveted to the boiler shell provided the maximum allowable working pressure on such a dome is computed with a factor of safety of not less than 8.

The dome may be located on the barrel or over the fire-box on traction, portable or stationary boilers of the locomotive type up to and including 48 in. barrel diameter. For larger barrel diameters, the dome shall be placed on the barrel.

Ques. What is the usual proportion of a steam dome?

Ans. The diameter and height is usually about one-half the diameter of the boiler.

The usual proportions for various size boilers are given in the following table:

Proportions of Steam Domes

For 100 pounds pressure

Diameter of boiler	Diameter of dome	Height of dome	Thickness of dome shell	Thickness of dome head
36	20	22	1/4	5/16
38	20	22	1/4	5/16
40	22	24	1/4	5/16
42	22	24	1/4	5/16
44	24	26	1/4	5/16
46	24	26	1/4	5/16
48	26	28	1/4	5/16
50	26	28	5/16	3/8
52	28	30	5/16	3/8
54	28	30	5/16	3/8
56	30	32	5/16	3/8
58	30	32	5/16	3/8
60	32	34	5/16	3/8
62	32	34	5/16	3/8
64	34	36	5/16	3/8
66	34	36	3/8	7/16
68	36	38	3/8	7/16
70	36	38	3/8	7/16
72	36	40	3/8	7/16

The Minor Openings.—The ordinary horizontal tubular boiler should be provided with:

1. Two main outlets for steam (one being for main steam supply and the other for supply to auxiliaries).

2. *An* ***independent*** *outlet* for injector only.

3. Two outlets for water column connections.
4. Opening for fusible plug.
5. Inlet for feed water.
6. Outlet for scum cock.
7. Outlet to blow off cock.

On vertical boilers the water column fixtures are usually connected direct to the shell, thus there will be in addition to the above, three openings for gauge cocks, two for water gauge, one for steam gauge. There is usually only one main steam outlet, the safety valve being attached to a branch connection from the outlet. On all boilers there should be a separate outlet for the injector, and ***steam should not be taken for any other purpose from this outlet.***

Figs. 3,973 to 3,975 show the minor openings for horizontal and vertical boilers.

The following table gives the usual proportions for the minor openings:

***A.S.M.E. Boiler Code.**—Threaded openings.*

268 An opening in a boiler for a threaded pipe connection 1 in. in diameter or over shall have not less than the number of threads given in Table 7.

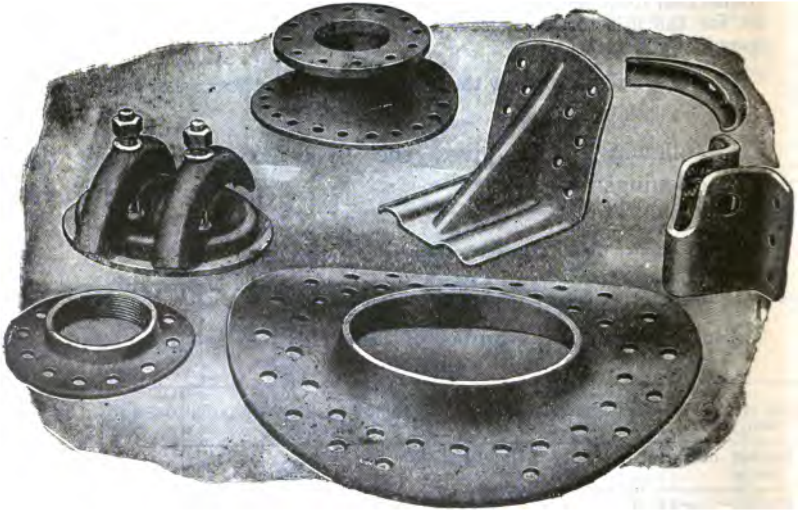
Table 7. Minimum Number of Pipe Threads for Connections to Boilers

Size of pipe connection, in.	1 and 1¼	1½ and 2	2½ to 4 inclusive	4½ to 6 inclusive	7 and 8	9 and 10	12
Number of threads per in.	11½	11½	8	8	8	8	8
Minimum number of threads required in opening	4	5	7	8	10	12	13
Minimum thickness of material required to give above number of threads, in.	0.348	0.435	0.875	1	1.25	1.5	1.625

If the thickness of the material in the boiler be not sufficient to give such number of threads, there shall be a pressed steel flange, bronze composition flange, steel-cast flange or steel plate, so as to give the required number of threads, constructed and riveted to the boiler in accordance with methods given in par. 261 (page 2,228). A steam main or safety valve opening may be fitted with either a steel cast, wrought-steel or bronze composition nozzle. A feed-pipe connection may be fitted with a brass or steel boiler bushing.

Minor Openings in Horizontal Tubular Boilers

Horse Power	45	50	60	70	75	100	125	150	175	200	225
Diameter of shell	48	48	54	54	60	60	72	72	78	78	84
Length of shell	12	14	14	16	14	16	16	18	18	20	20
Size of main outlet	3	3	3	3½	3½	5	5	5	6	6	6
Size of auxiliary outlet	2½	2½	2½	2½	3	3½	4	4	4½	5	5
Size of blow off outlet	2½	2½	2½	2½	2½	2½	2½	2½	2½	2½	2½
Size of water column outlet	1¼	1¼	1¼	1¼	1¼	1¼	1¼	1¼	1¼	1¼	1¼
Size of feed water inlet	1¼	1¼	1½	1½	1½	1½	1½	1½	1½	2	2



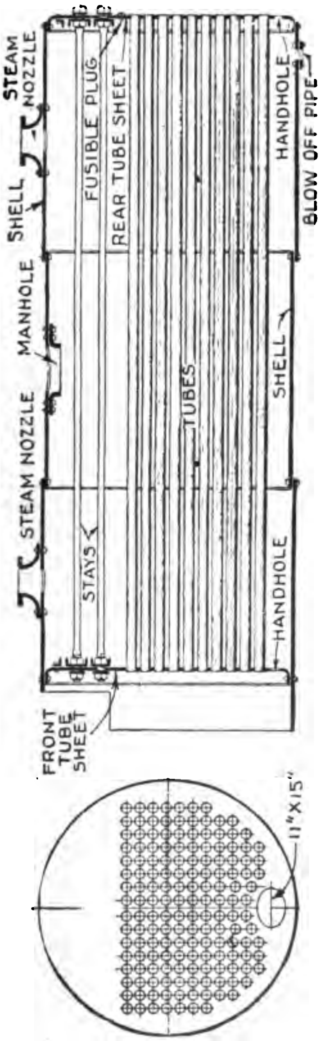
FIGS. 3,966 to 3,972.—Bigelow pressed steel boiler parts. Such parts as lugs, hangers, man hole saddles, man hole plates, nozzles and mouldings for the fronts are made of pressed steel instead of cast iron. The advantage of this construction over cast iron must be apparent.

Ques. What are nozzles?

Ans. Short flanged nipples riveted to the main steam outlets.

Ques. Of what material should nozzles be made?

Ans. Of pressed steel.



FIGS. 3,973 and 3,974.—*Minor openings* in a horizontal boiler.

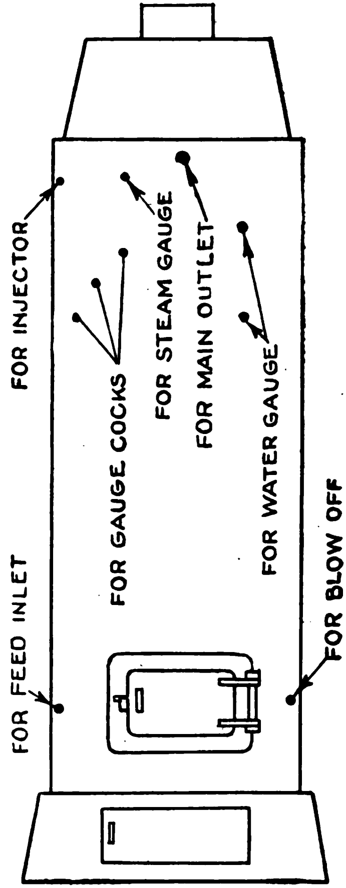


FIG. 3,975.—*Minor openings* in a vertical boiler. In this type boiler the fusible plug is tapped into one of the fire tubes, being reached through a hand hole at the low water level.

PROPERTIES OF "NATIONAL" STATIONARY AND MARINE BOILER TUBES

Diameter		Thickness		Circumference		Transverse Area			Length of Tube per Square Foot		Length of Tube Containing One Cu Ft	WEIGHT PER FOOT
External	Internal			External	Internal	External	Internal	Metal	External Surface	Internal Surface		
Inches	Inches	Inches	B.W.G	Inches	Inches	Square Inches	Square Inches	Square Inches	Feet	Feet	Feet	POUNDS
1	.810	.095	13	3.142	2.545	.785	515	270	3 820	4 716	279 449	.918
1¼	1.060	.095	13	3.927	3.330	1.227	882	.345	3 056	3.604	163 178	1.171
1½	1.310	.095	13	4.712	4.115	1.767	1.348	.419	2.546	2.916	106 839	1.425
1¾	1.560	.095	13	5.498	4.901	2.405	1.911	.494	2 183	2.449	75.340	1.679
2	1.810	.095	13	6.283	5 686	3.142	2.573	.569	1.910	2.110	55.965	1.932
2¼	2.060	.095	13	7 069	6.472	3.976	3.333	.643	1.698	1.854	43.205	2.186
2½	2.282	.109	12	7.854	7 169	4.909	4.090	.819	1.528	1.674	35.208	2.783
2¾	2.532	.109	12	8.639	7.955	5.940	5.036	.904	1.389	1.509	28 599	3.074
3	2.782	.109	12	9.425	8.740	7.069	6.079	.990	1.273	1.373	23.690	3.365
3¼	3.010	.120	11	10.210	9.456	8.296	7.116	1.180	1.175	1.269	20.237	4.011
3½	3.260	.120	11	10.996	10.242	9.621	8.347	1.274	1.091	1.172	17.252	4.331
3¾	3.510	.120	11	11.781	11.027	11.045	9.677	1.368	1.019	1.088	14.882	4.652
4	3.732	.134	10	12.566	11 724	12.566	10.939	1.627	.955	1.024	13.164	5.532
4½	4 232	.134	10	14.137	13.295	15.904	14.066	1.838	.849	.903	10.237	6.248
5	4.704	.148	9	15.708	14 778	19 635	17.379	2.256	.764	.812	8.286	7.669
6	5.670	.165	8	18.850	17.813	28.274	25.249	3.025	.637	.674	5.703	10.282
7	6.670	.165	8	21.991	20.954	38.485	34.942	3.543	.546	.573	4.121	12.044
8	7.670	.165	8	25.133	24.096	50.265	46.204	4.061	.477	.498	3.117	13.807
9	8.640	.180	7	28.274	27.143	63.617	58.629	4.988	.424	.442	2.456	16.955
10	9.594	.203	6	31.416	30.140	78.540	72.292	6.248	.382	.398	1.992	21.240
11	10.560	.220	5	34.558	33.175	95.033	87.582	7.451	.347	.362	1.644	25.329
12	11.542	229		37.699	36.260	113.097	104.629	8.468	.318	.331	1.376	28.788
13	12.524	.238	4	40.481	39.345	132.732	123.190	9.542	.294	.305	1.169	32.439

The use of cast iron for nozzles or in fact for any other part that is under pressure in a moderate or high pressure boiler should not be allowed; its properties are about as foreign to the requirements of the job as is concrete in ship construction.

Boiler Tubes.—These are listed and described from the *outside diameter*. This should be noted, as wrought pipe is described from the *inside diameter*. Thus a 1 inch pipe is nearly 1¼ outside diameter while a 1 inch boiler tube is exactly one inch.

The table on page 2,238 gives the "properties" of stationary and marine boiler tubes.

A.S.M.E. Boiler Code.—Tubes.

21 *Tubes for Water Tube Boilers.* The minimum thickness of tubes used in water tube boilers measured by Birmingham wire gauge, for maximum allowable working pressures not exceeding 165 lb. per sq. in., shall be as follows:

Diameters less than 3 in.	No. 12 B.W.G.
Diameter 3 in. or over, but less than 4 in.	No. 11 B.W.G.
Diameter 4 in. or over, but less than 5 in.	No. 10 B.W.G.
Diameter 5 in.	No. 9 B.W.G.

The above thicknesses shall be increased for maximum allowable working pressures higher than 165 lb. per sq. in. as follows:

Over 165 lb. but not exceeding 235 lb.	1 gauge
Over 235 lb. but not exceeding 285 lb.	2 gauges
Over 285 lb. but not exceeding 400 lb.	3 gauges

Tubes over 4-in. diameter shall not be used for maximum allowable working pressures above 285 lb. per sq. in.

22 *Tubes for Fire Tube Boilers.* The minimum thicknesses of tubes used in fire tube boilers measured by Birmingham wire gauge, for maximum allowable working pressures not exceeding 175 lb. per sq. in., shall be as follows:

Diameters less than 2½ in.	No. 13 B.W.G.
Diameter 2½ in. or over, but less than 3¼ in.	No. 12 B.W.G.
Diameter 3¼ in. or over, but less than 4 in.	No. 11 B.W.G.
Diameter 4 in. or over, but less than 5 in.	No. 10 B.W.G.
Diameter 5 in.	No. 9 B.W.G.

For higher maximum allowable working pressures than given above the thicknesses shall be increased one gauge.

164 *Process.* *a* Lapwelded tubes shall be made of open-hearth steel or knobbled hammered charcoal iron.

b Seamless tubes shall be made of open-hearth steel.

169 *Hydrostatic Tests.* Tubes under 5 in. in diameter shall stand an internal hydrostatic pressure of 1,000 lb. per sq. in. and tubes 5 in. in diameter or over, an internal hydrostatic pressure of 800 lb. per sq. in. Lapwelded tubes shall be struck near both ends, while under pressure, with a two-pound hand hammer or the equivalent.

U.S. Marine Rules.—Tubes.

II-15 Lapwelded and seamless tubes, used in boilers whose construction was commenced after June 30, 1910, having a thickness of material according to their respective diameters, shall be allowed a working pressure as prescribed in the following table, provided they are deemed safe by the inspectors. Any length of tube is allowable.

Outside diameter.	Thickess of Material	Maximum pressure allowed	Outside diameter.	Thickness of material.	Maximum pressure allowed.
Inches.	*Inch.*	*Pounds.*	*Inches.*	*Inch.*	*Pounds.*
2	.095	427	3½	.120	308
2¼	.095	380	3¾	.120	282
2½	.109	392	4	.134	303
2¾	.109	356	4½	.134	238
3	.109	327	5	.148	235
3¼	.120	332	6	.165	199

Another difference between boiler tubes and wrought pipe consists in the fact that the outside of boiler tubes is smooth and even, while wrought pipe is left comparatively rough and uneven.

Boiler tubes were formerly most commonly made of charcoal iron and lap welded, but the present tendency is to use seamless and lap welded steel tubes. In the formation of the lap of a lap welded tube, the plate is upset, then bent around until the thickened edges lap sufficiently. It is then heated progressively about 8 inches at a time, and welded over a mandrel, consisting of a cast iron arm, with a slightly convex top over which the tube is placed.

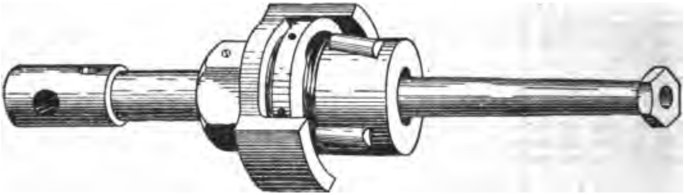


FIG. 3,976.—Roller tube expander. ***It consists of*** a set of rolls placed in a cage and in contact with a central tapered pin. ***In operation*** the rolls are faced against the inside of the tube by driving in the turning and forcing in the taper pin. The rolls rotate with the pin and gradually expand the tube against the tube sheet.

Seamless tubes are manufactured from solid billets by passing the billet heated white hot through a piercing mill. The billet is forced over a stationary piercing point of malleable iron by the forwarding and revolving action of heavy rotary discs, enormous power being applied to displace the metal from the center of the hot billet.

Holding Power of Boiler Tubes.—Experiments by Yarrow & Co., on steel tubes 2 to 2½ inches in diameter, expanded into tube sheets gave varying results, ranging from 7,900 to 41,715 pounds, the majority ranging

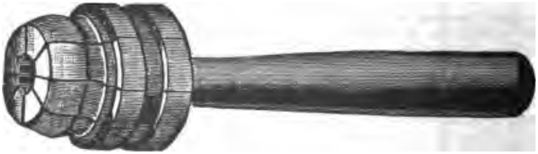


FIG. 3,977.—Prosser segment tube expander. ***It consists of*** a number of segments and a taper pin. The segments are held in place by a spring. The outside surface of the segments have the form to be given to the expanded tube, and the inside is a straight hollow cone into which the steel taper pin fits. ***In operation*** the segments are forced apart in expanding the tube by hammering on the steel pin. This type of expander requires careful handling in order not to injure the tube. The hammering should be done gradually and the expander turned frequently.

from 20,000 to 30,000 pounds. In 15 experiments on 4 and 5-inch tubes the strain ranged from 20,720 to 68,040 pounds. Beading the tube does not necessarily give increased resistance, as some of the lower figures were obtained with beaded tubes.

Ques. How are boiler tubes fastened to the heads or tube sheets?

Ans. By expanding the metal of the tube against the tube plate with a *tube expander* and then beading over the ends with a *beading tool*.

Figs. 3,976 and 3,977 show two forms of tube expanders in general use, and fig. 3,978 a beading tool.

U.S. Marine Rules.—Tubes.—Continued

LAP WELDED BOILER TUBE UP TO AND INCLUDING 4 INS. IN DIAMETER.

All lap welded tubes shall be made of charcoal iron or mild steel made by any process.

Each tube shall stand an internal hydrostatic pressure of 1,000 pounds per square inch and shall be struck near both ends while under pressure with a 2-pound hammer or its equivaent without showing signs of weakness or defects.

All steel tubes, except those made of open-hearth steel, shall have the ends properly annealed by the manufacturer before shipment.

All steel tubes shall stand expanding flanging over on the tube plate, and beading without flaws cracks, or opening at the weld.

All lap welded boiler tubes over 4 inches in diameter, up to and including 30 inches in diameter, shall be made of wrought iron or mild steel made by any process.

LAP WELDED BOILER TUBES OVER 4 INCHES UP TO AND INCLUDING 30 INCHES IN DIAMETER.

Each tube shall stand an internal hydrostatic pressure of 800 pounds per square inch and shall be struck near both ends while under pressure with a 2-pound hammer or its equivalent without showing signs of weakness or defects.

All steel tubes except those made of open-hearth steel shall have ends properly annealed by the manufacturer before shipment.

SEAMLESS STEEL BOILER TUBES.

All steel tubes shall stand drilling, riveting, and culking and work necessary to install them into the tube head without showing any weakness or defects.

No tube increased in thickness by welding one tube inside of another shall be allowed for use, but the ends of boiler tubes may be welded on for the purpose of making repairs or new tubes may be welded for the purpose of making seamless steel boiler tubes them longer.

All seamless steel boiler tubes shall be made of open hearth steel.

Each tube shall be subjected to an internal hydrostatic pressure of 1,000 pounds per square inch without showing signs of weakness or defects.

All tubes shall stand expanding, flanging over on the tube plate, and beading without flaw or crack.

Fire Doors.—In the case of vertical boilers, it is necessary to provide an opening through both furnace and outer shell for firing. The constructions of this opening are shown in figs. 3,979 to 3,982.

The simplest is the use of the ring indicated in fig. 3,979, and perhaps the most common is that indicated in fig. 3,982. In all cases the plates are riveted together or against the ring and caulked to give a tight joint.

Figs. 3,983 to 3,985 show special construction of fire door openings.

Doors are made of cast iron and should be sufficiently large to permit of

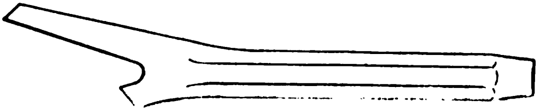
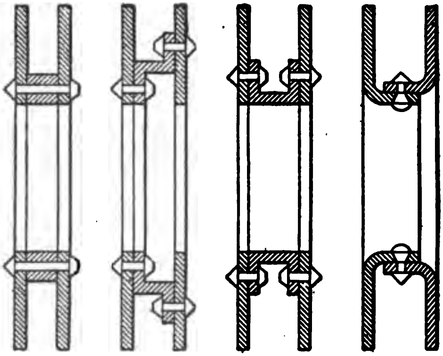


FIG. 3,978.—Beading tool.



FIGS. 3,979 to 3,982.—Various fire-door openings for vertical boilers.

NOTE.—***Spellerizing.***—This is a method of treating metal which consists in subjecting the heated bloom to the action of rolls having regularly shaped projections on their working surfaces, then to the action of smooth faced rolls, and repeating the operation, whereby the surface of the metal is worked so as to produce a uniformly dense texture, better adapted to resist corrosion, specially in the form of pitting. Boiler tubes are sometimes spellerized.

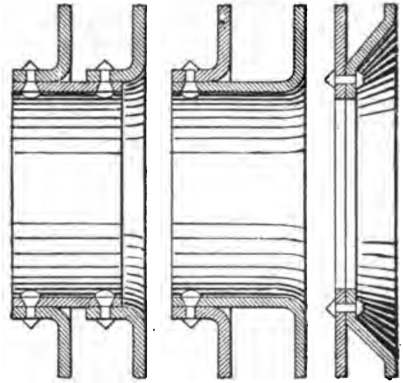
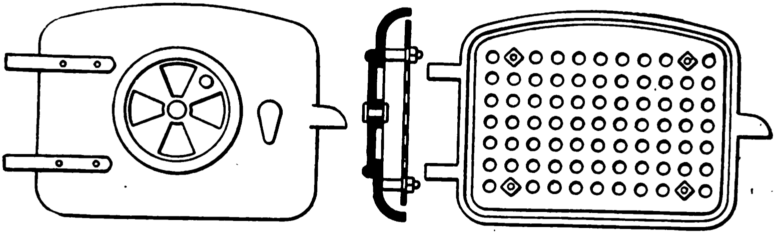
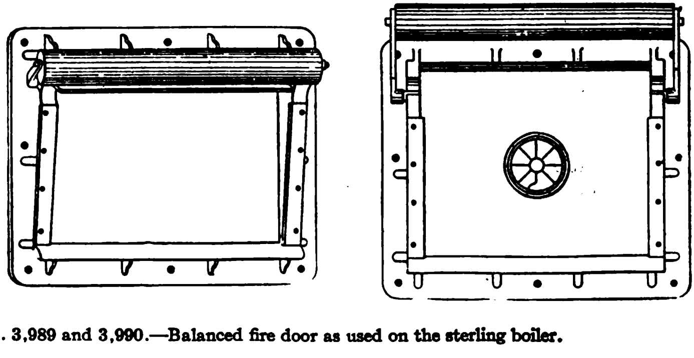


FIG. 3,983 to 3,985.—Special constructions of fire-door openings.



FIGS. 3,986 to 3,988.—Views of ordinary fire door, showing damper and baffle plate.



FIGS. 3,989 and 3,990.—Balanced fire door as used on the sterling boiler.

the convenient handling of shovel, slice bar and hoe to the back of the fire. The opening is usually at least 12 inches high by 10 inches wide and runs from this to 16×20. For wide grates two small doors are preferable to one large one.

The door proper is protected on the inside by a lining plate of cast iron which should be perforated so that air entering the damper of the door will be divided into fine streams. These plates must be made renewable, as they are likely to be warpt and cracked by the heat.

Two forms of fire doors are shown in figs. 3,986 to 3,990, one in particular showing the balanced doors used by the Stirling Boiler Co., which is opened and closed up by a push on the counterweight which is outside the boiler. In some plants the doors are covered with an asbestos coating on the outside and in others are given a coat of white paint to lessen the radiation and discomfort to the fireman.

WATER TUBE BOILER CONSTRUCTION

Steam Drums.—The great variety of ways in which the water tube principle can be applied in the design of a water tube boiler gives rise to a multiplicity of drum types. These may be classified:

1. With respect to position, as
    - *a.* Longitudinal.
    - *b.* Transverse.
2. With respect to function as
    - *a.* Steam.
    - *b.* Water.
    - *c.* Mud.
3. With respect to mechanical arrangement as
    - *a.* Tapped.
    - *b.* Header.
    - *c.* Manifold.

4. With respect to circulation as
    - *a.* Over or dry discharge.
    - *b.* Under or wet discharge.

Most boilers have longitudinal drums, because this gives a longer drum, thus obtaining greater *liberating surface*.

Transverse drums are used on some marine boilers and others where there is little head room, necessitating a low boiler.

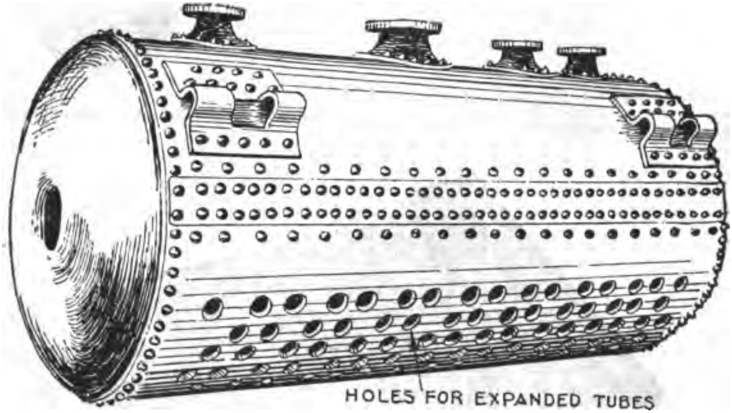


Fig. 3,991.—Ladd transverse steam drum with holes for expanded tubes. ***In construction*** the drums are of one or two sheets without circumferential sheet seams. The longitudinal seams are above the roof tile, the head seams being protected by the side walls. The manhole covers are of the un-swinging type, and all flanges and connections are of wrought metal.

On boilers of small and medium size there is usually only one drum for the steam and water (called the *steam* drum), the water line coming about the center of the drum, separate drums for water and steam represent additional complication which is not necessary.

On very large boilers there may be several drums. In fact, the water tube principle lends itself to a very flexible construction, that is, boilers may be designed for practically any capacity, and also to fit almost any shaped volume.

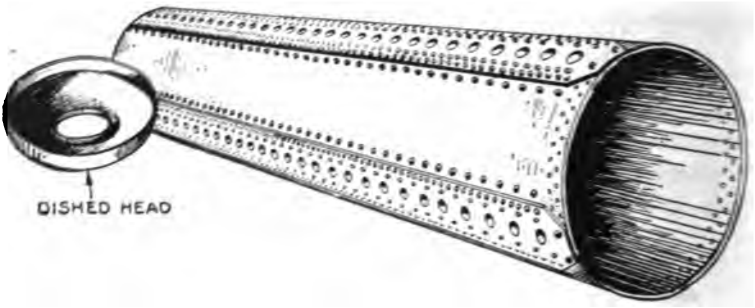


Fig. 3,992.—Babcock and Wilcox marine transverse drum with holes bored for tubes leading to the upflow and down flow headers. These are *expanded joints* for tubes as distinguished from *tapped or screwed joints* as used in *pipe boilers*.

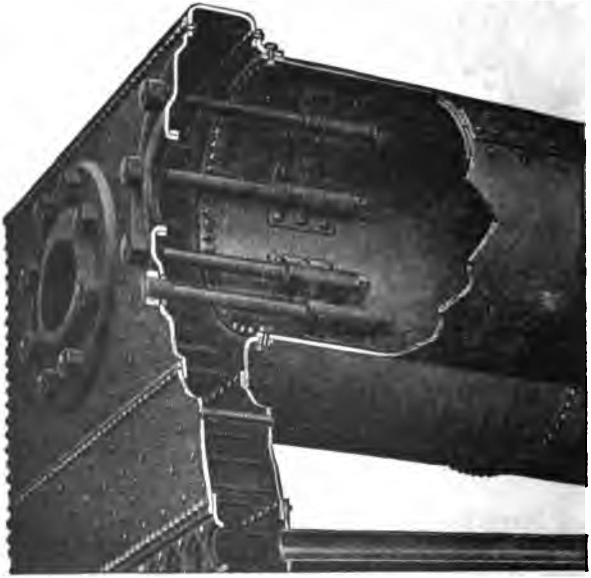


Fig. 3,993.—Edge Moor longitudinal header drum connection with header on two drum boiler showing part of header and arrangement of stays.

Tapped Drums.—Fig. 3,992 shows a typical drum of this type which is tapped on each side along its length for connection with the pipe section ends. Where tubes are used instead of pipes they are expanded into the drum instead of connected by threaded joints.

Header Drums.—On boilers in which the tubes are expanded into headers, the drums instead of having rows of holes for the upflows, have a large opening at each end, each connecting with a leader. In some designs the entire drum end is riveted to the header as shown in fig. 3,993. The first mentioned construction is shown in fig. 3,994, in which only part of the drum end is on communication with the header.

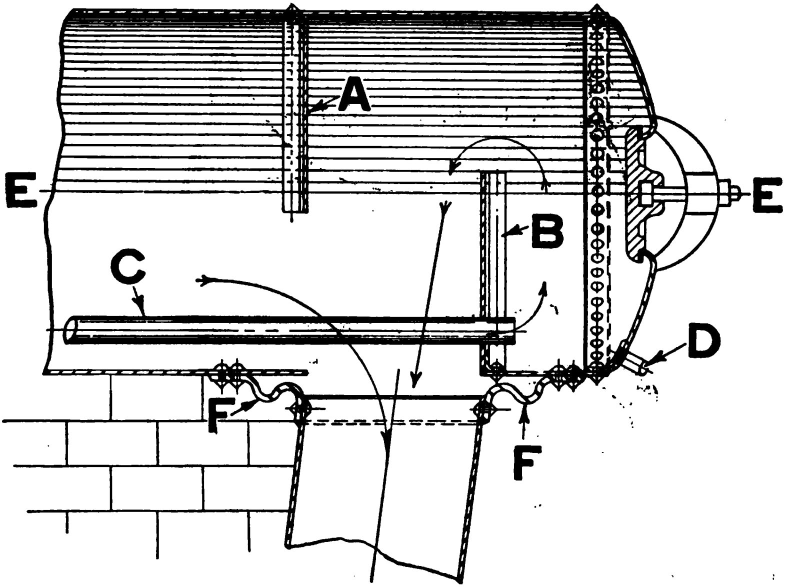
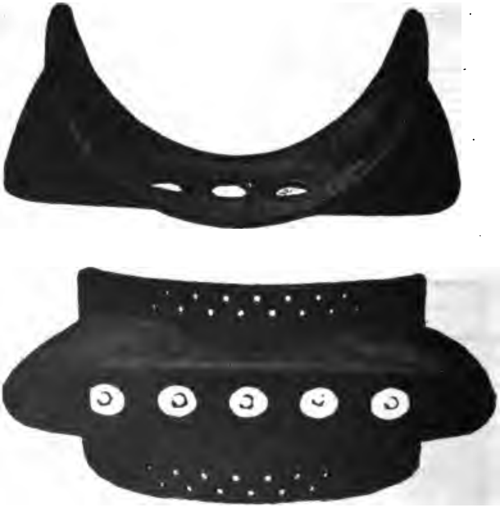


FIG. 3,994.—Union Iron Works longitudinal header drum end showing connection with header and method of feed water delivery. ***The lettered parts are:*** **A**, front diaphragm; **B**, rear diaphragm; **C**, feed water pipe; **D**, sediment blow off; **E**, water level; **F**, corrugated connection. The feed water is brought in at the front end of the drum, carried through to the rear of the drum in an internal feed pipe which liberates the water into the purifying chamber. The water when liberated is at the boiling point and precipitation of the solids and other impurities takes place readily. These deposits settle in the bottom of the chamber and are blown off by blow off pipe **D**. Baffles **A** and **B** show the method of isolating purifier and conducting water from same down the rear header connection without obstructing the circulation from the front to the rear of the drum. Special provision can be made to prevent deposits in the feed pipe, where water is highly saturated with lime, magnesia or other solid matter.

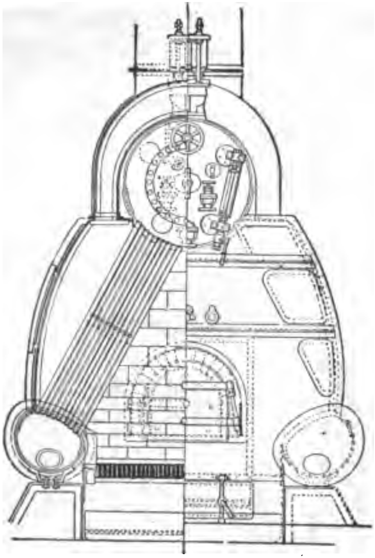
Manifold Drums.—These, instead of being connected to a header at each end, are provided with cross boxes which have a number of tapped holes for connection to manifolds or small headers. Figs. 3,995 and 3,996 show one of the cross boxes, the drum construction in other respects being similar to the header drum previously described.

Over and Under Discharge Drums.—According to the requirements of the service for which a boiler is designed, the upflow tubes may be arranged to discharge into the drum either *below* or *above* the water level. The first type is sometimes called *drowned tube*, because the tubes are always covered with water. Fig. 3,997 shows this type as built for marine service, and fig. 3,998, an over discharge or dry tube in which all the upflow tubes discharge above the water. The object of the arrangement, as must be evident is to obtain a low center of gravity.



Figs. 3,995 and 3,996.—Views of Babcock and Wilcox cross box which forms a connection between the drum and the numerous manifolds or small sectional headers. The box is made of forged steel.

Water and Mud Drums.—The Vogt boiler will serve to illustrate the destruction between these drums and in fact it shows all three kinds of drums as classified. In the "parallel series" arrangement of the tubes in



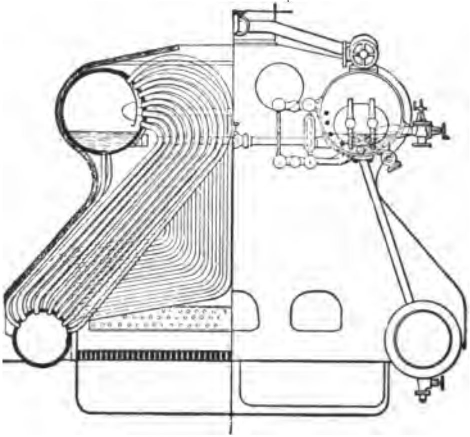
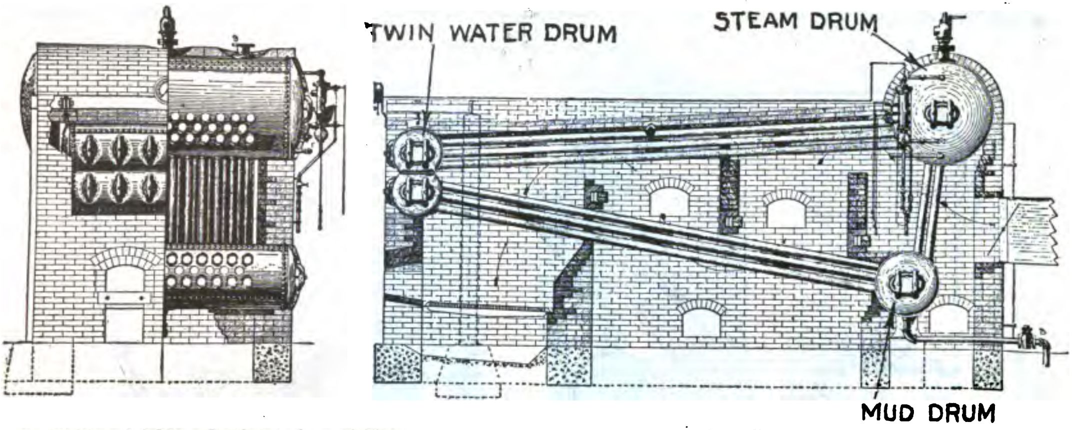


FIG. 3,997.—Yarrow straight tube longitudinal drum ***under discharge*** marine boiler.

FIG. 3,998.—Mosher bent tube double longitudinal drum ***over discharge*** marine boiler. This type of boiler is suitable for high-speed launches and torpedo boats when a ***low*** center of gravity is required. This boiler has two upper and two lower drums, which are connected by rows of bent tubing, inclined and connected, above and below, as shown. The two upper drums are also connected, below the water line, by a length of tubing, thus completing the water circulation.

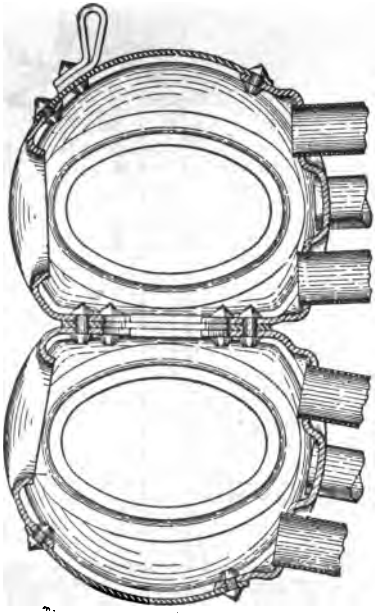


FIGS. 3,999 and 4,000.—Sectional views of Vogt, Class F, transverse drum water tube boiler ***illustrating the distance between steam, water and mud drums.*** This boiler is designed for limited head room. The feed water enters ***steam drum*** in head underneath man hole and is distributed directly above the vertical bank of tubes in rear end, and passes to the ***mud drum,*** then through the two horizontally inclined banks of tubes back into the ***steam drum.*** Vertical baffles are used, giving a 3-pass flow of the hot gases.

the Vogt boiler the twin tranverse water drums forms the "*series*" connection between the two masses of tubes; this feature is shown in figs. 3,999 and 4,000, the construction being shown in detail in fig. 4,001.

The mud drum, as shown in fig. 4,000 is simply a cylindrical chamber with blow off connection tapped to its lowest point.

In some boilers instead of a mud drum, sediment pockets are provided as shown in fig. 4,003.



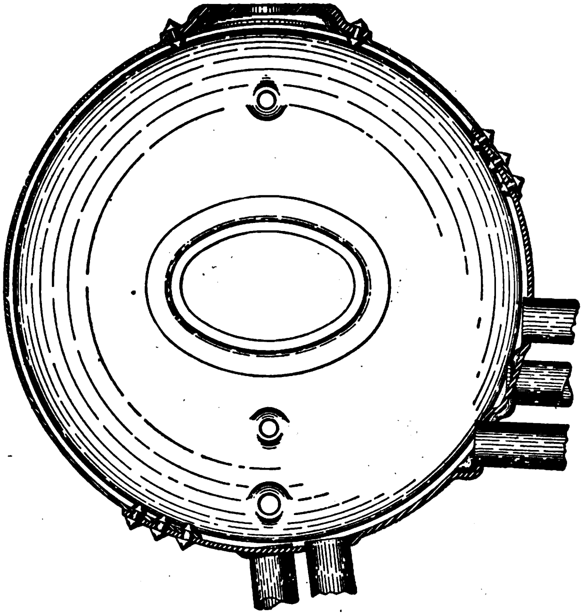


FIG. 4,001.—Detail of Vogt twin traverse ***water drum,*** showing plate between and openings for circulation.

FIG. 4,002.—Detail of Vogt ***steam drum.***

Headers and Manifolds.—These form the connecting links between the tubes and drum or drums. Usually all the tubes are expanded into one header at each end, but

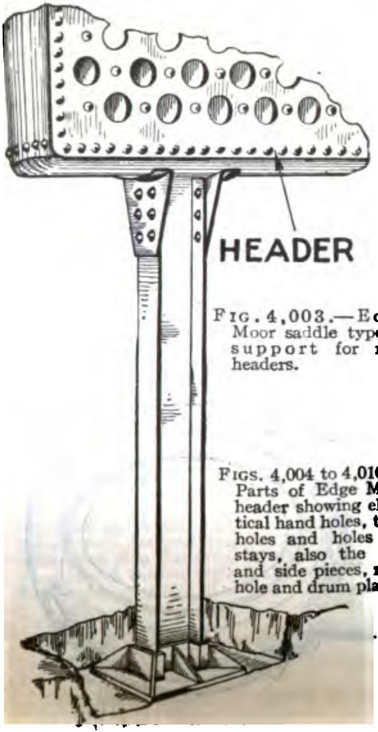
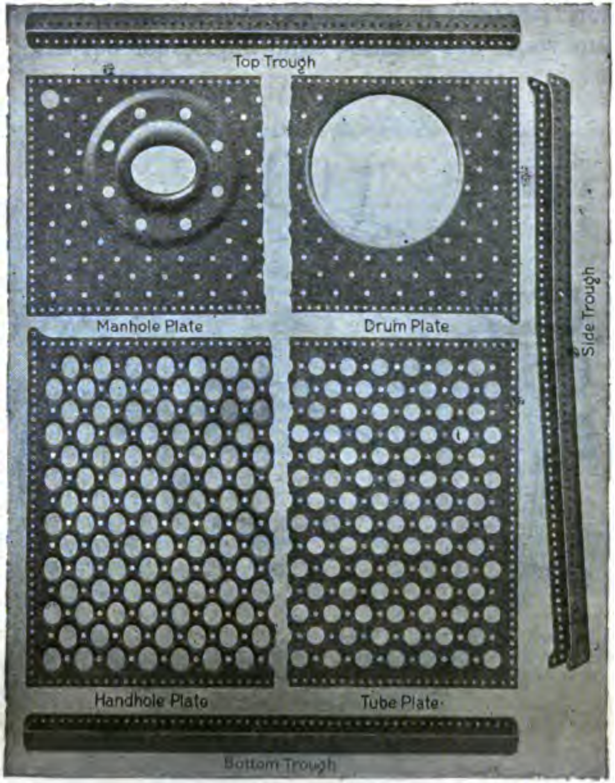


FIG. 4,003.—Edge Moor saddle type of support for rear headers.

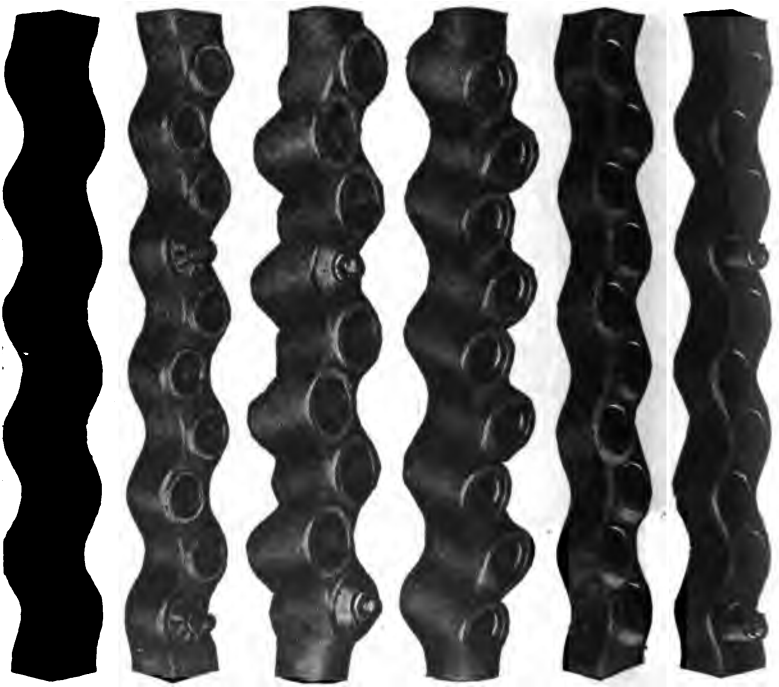


FIGS. 4,004 to 4,010.—Parts of Edge Moor header showing elliptical hand holes, tube holes and holes for stays, also the end and side pieces, man hole and drum plates.

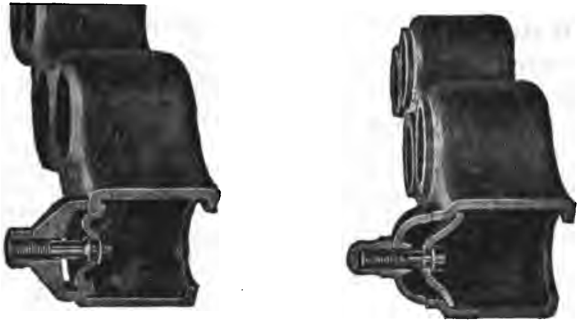
where the tubes are divided up into groups as in "sectional" water tube boilers, in place of one large header at each end, there are a number of small headers or manifolds.

Figs. 4,011 to 4,013.—Construction of Edge Moor header hand hole plate. Fig. 4,011, elliptical holes are first punched in the blank plate by means of a combined punch and spacing mechanism; fig. 4,012, the plate is then heated to a cherry red and the holes are forged to shape between multiple dies; fig. 4,013, a multiple spindle machine faces the edges and automatically spaces and drills the holes for the stays.

Figs. 4,004 to 4,010 show the parts of an Edge Moor header, and fig. 4,022 a portion of the header assembled. Figs. 4,014 to 4,021 show typical manifold sectional header construction.



FIGS. 4,014 to 4,019.—Babcock and Wilcox sectional headers or ***manifolds.*** Fig. 4,014 and 4,015, wrought steel vertical header; figs. 4,016 and 4,017, wrought steel inclined header; figs. 4,018 and 4,019 cast iron header. For pressures up to 160 pounds, cast iron headers are used. The headers, as shown, may be either vertical or inclined. Opposite each tube end in the headers is placed a hand hole of sufficient size to permit the cleaning, removal or renewal of a tube. These openings in the wrought-steel vertical headers are elliptical in shape, machine faced, and milled to a true back from the edge a sufficient distance to make a seat. The openings are closed by inside fitting forged plates, shouldered to center in the opening, their flanged seats milled to a true plane. These plates are held in position by studs and forged steel binders and nuts, the joints between plates and manifolds are made with a thin gasket. In the wrought steel inclined manifolds the handhole openings are either circular or elliptical, the former being ordinarily supplied. The circular openings have a raised seat milled to a true plane. The openings are closed on the outside by forged steel caps, milled and ground true, held in position by forged steel safety clamps and secured by ball headed bolts to assure correct alignment. With this style of fitting, joints are made tight, metal to metal, without packing of any kind. Where elliptical hand holes are furnished they are faced inside, closed by inside fitting forged steel plates, held to their seats by studs and secured by forged steel binders and nuts. The joints between plates and manifolds are made with a thin gasket. The vertical cast iron manifolds have elliptical hand holes with raised seats milled to a true plane. These are closed on the outside by cast iron caps milled true, held in position by forged steel safety clamps, which close the openings from the inside and which are secured by ball headed bolts to assure proper alignment. All joints are made tight, metal to metal, without packing of any kind.



Figs 4,020 and 4,021.—Hand hole fittings. Fig. 4,020 ***inside hand hole fitting*** for wrough steel ***vertical manifold;*** 4,021 ***outside hand hole*** fitting for wrought steel ***inclined manifold***

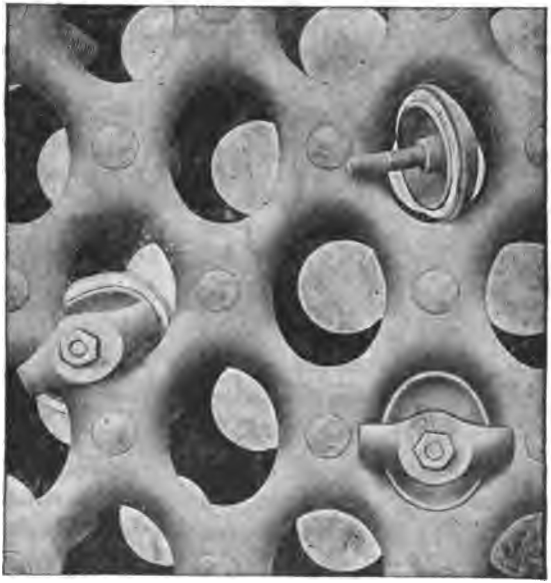
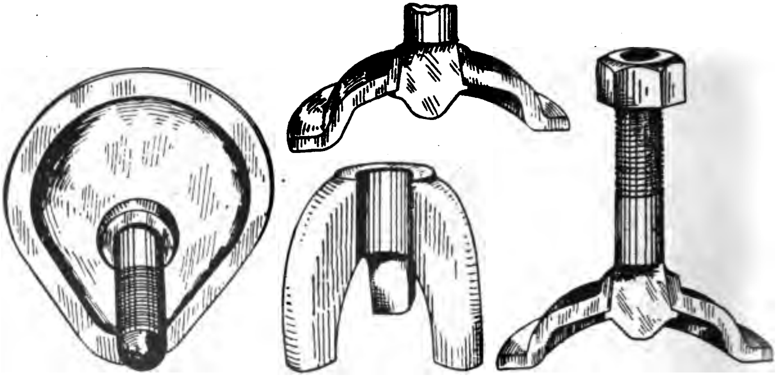


Fig. 4,022.—Portion of Edge Moor header assembled showing elliptical hand holes. The elliptical hand holes make it possible to pass every cover through its own handhole instead of from one hole to another. The covers bear against the *inside* of the header plate. No special make of gasket is required. The edges of the hand hole plate are flanged inward, the upturned edges being faced in a special machine.

Feed Water Heaters.—One of the component parts of some types of water tube boilers, especially those intended for marine service, is a feed water heater placed within the casing, comprising about 20 to 30 per cent. of the total heating surface.

The feed water after passing through the heater and its temperature raised to the boiling point, enters the boiler proper. Fig. 3,685 page (2,075) shows one section or so-called "feed coils" of a typical heater as used on the Roberts boiler. In assembling, one of these coils is placed on each side of the drum above the main heating surface, and the two connected in ***series parallel***, to feed line and drum as shown on page 2,075.



Figs. 4,023 to 4,026.—Union Iron Works component parts of hand hole plate complete with both nut and yoke for same. These plates are made of steel, fit on the inside (or pressure side) of header plate and withdraw through the hole they cover. The bolt is securely riveted to the plate in a hydraulic riveter and the yoke is of unique construction, permitting its quick removal by simply loosening the nut a few turns, leaving the nut on the stud, thus eliminating losses of same.

Superheaters.—Nearly all water tube boilers are provided with superheaters, the great saving due to superheating now being fully recognized. Steam, when first formed as in a boiler is known as saturated steam, the temperature of which depends on the pressure. To add more heat to a boiler in which water is present would merely result in the production of more saturated steam with increase of pressure. A superheater serves to separate the steam from the presence of the water and expose it to the heat of furnace gases, which results in superheat.

The amount of heat which may be added to steam in a superheater is independent of the pressure and is limited only by the ability of the metal to withstand the high temperature.

This amount reaches the practical limit with ordinary materials of

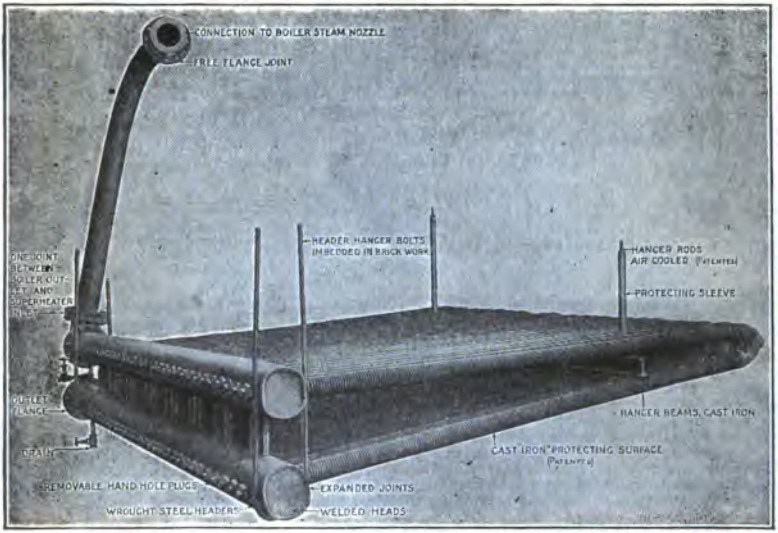

CONNECTION TO BOILER STEAM NOZZLE
FREE FLANGE JOINT
ONE JOINT BETWEEN BOILER OUTLET AND SUPERHEATER INLET
HEADER HANGER BOLTS IMBEDDED IN BRICK WORK
HANGER RODS AIR COOLED (PATENTED)
PROTECTING SLEEVE
OUTLET FLANGE
HANGER BEAMS, CAST IRON
DRAIN
CAST IRON PROTECTING SURFACE (PATENTED)
REMOVABLE HAND HOLE PLUGS
EXPANDED JOINTS
WROUGHT STEEL HEADERS
WELDED HEADS

Fig. 4,027.—Foster superheater assembled for use in horizontal water tube boiler with vertical baffling.

A.S.M.E. Boiler Code.—Superheaters.

252 The ends of tubes, suspension tubes and nipples shall project through the headers not less than ¼ in., nor more than ½ inch before flaring.

288 Every superheater shall have one or more safety valves near the outlet. The discharge capacity of the safety valve or valves on an attached superheater may be included in determining the number and sizes of the safety valves for the boiler, provided there are no intervening valves between the superheater safety valve and the boiler.

289 Every safety valve used on a superheater, discharging superheated steam, shall have a steel body with a flanged inlet connection and shall have the seat and disc of nickel composition or equivalent material, and the spring fully exposed outside of the valve casing so that it shall be protected from contact with the escaping steam.

306 Each superheater shall be fitted with a drain.

construction at, approximately, 1,000° Fahrenheit as a final temperature, which represents, as superheat, the difference between the temperature of saturated steam at the pressure under consideration, and 1,000°. Fig. 4,027 show an approved form of superheater extensively used in both water tube and fire tube boilers.

***Location of Superheater.**—A much used location for a superheater is inside the boiler setting at a point in a water tube boiler between the tubes and the shell. With the arrangement the steam is passed from the boiler, through the superheater into the steam main to the engines.

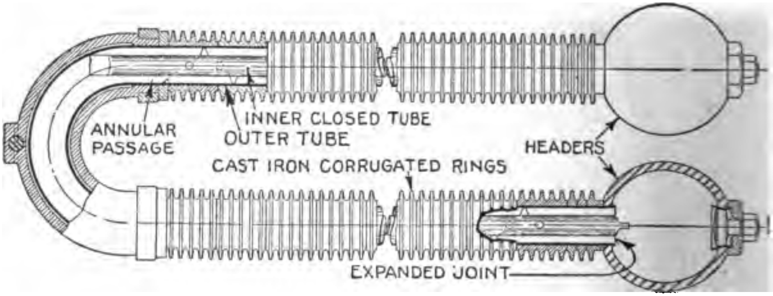


FIG. 4,028.—Construction detail of Foster superheater element. ***In assembling,*** groups of U-shaped elements, as shown, are joined ***in parallel*** to manifolds or connecting headers. Series of cast iron annular gills or flanges, placed close to each other, are carefully fitted to the outside of the tube so as to be practically integral therewith, thus exposing an external surface of cast iron, to contact with the heated gases. The rings or annular gills are carefully bored to gauge and shrunk on the tubes. Once being in position, the rings and tubes act practically as a unit. As the coefficient of expansion of steel is a trifle greater than that of cast iron, the rings grip the tubes even tighter when the temperature is increased as is the case when the superheater is in service. The mass of metal in the tubes and covering acts as a reservoir for heat. Inside the elements are placed *closed* tubes of smaller diameter, centrally supported on ***knobs*** to form a thin annular passage for steam between the inner and outer tubes, thus dividing the steam flow into three annular streams. The joints at the ends of the elements are made by expanding the steel tubes into wrought steel headers.

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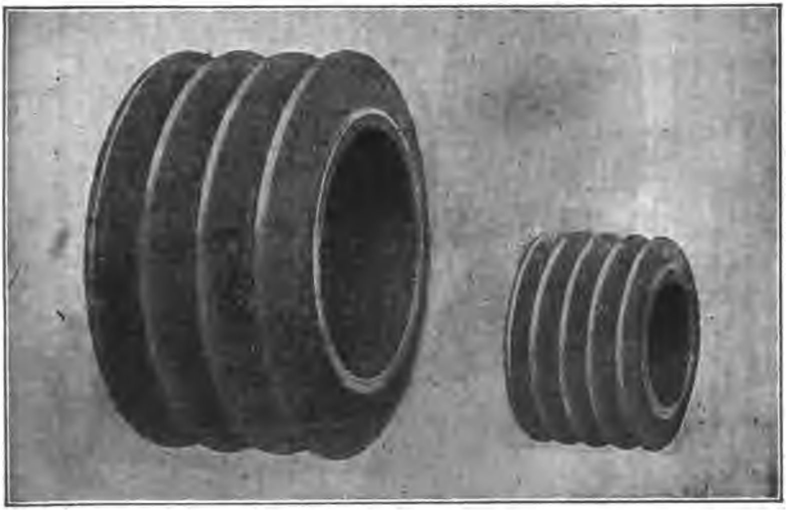
*NOTE.—The question as to the proper location in which to place the superheating device has received a good deal of attention and been the subject of a great deal of experiment, but still remains perhaps a matter of discussion. First there is the possible location of the superheater in the main flue where it is exposed to the gases of combustion after they have left the boiler and are to be allowed to escape. At first thought this location seems attractive from the fact that any heat obtained in this way is a direct saving and that the superheating would cost nothing. Further consideration, however, shows that in a properly designed and operated plant practically no superheating at this point is possible for the reason that with a boiler operating under 150 lbs. pressure good practice would call for a release of the combustion gases at a temperature not much exceeding 500°F., which temperature is necessary to maintain a natural chimney draught sufficiently strong to burn a common grade of bituminous coal. Again it will be found that while existing conditions may be such as to make it possible to install the superheater in the flue and show a small increase in economy due to the increase in temperature, yet, by placing an economizer in the same location, through which the feed water may be passed on its way to the boiler, a much greater gain would result. The reason for this is that the transfer of heat depends upon the difference of temperatures. This difference in the case of an attempt to superheat the steam would be only 100°F., to 200°F., while in the case of feed water it would be from 200°F. to 400°F., so that the saving due to an economizer would be several times greater than could possibly result from the use of the superheater.

Ques. What must be done in starting up a cold boiler with a superheater located as just described?

Ans. The superheater being exposed to a very high temperature, must be flooded with water until the boiler is generating steam freely.

Ques. What ill effect results from this flooding?



FIGS. 4,029 and 4,030.—Cast iron corrugated rings forming the external protective covering of Foster superheater elements.

Ans. It causes a deposit of scale at a location where, in some types of superheater it is impossible to remove.

The flooding and draining of a superheater is in no sense a difficult operation, but still it is one more operation to be performed when cutting a boiler into and out of service and is best avoided if possible.

Another plan of locating the superheater is to place it higher

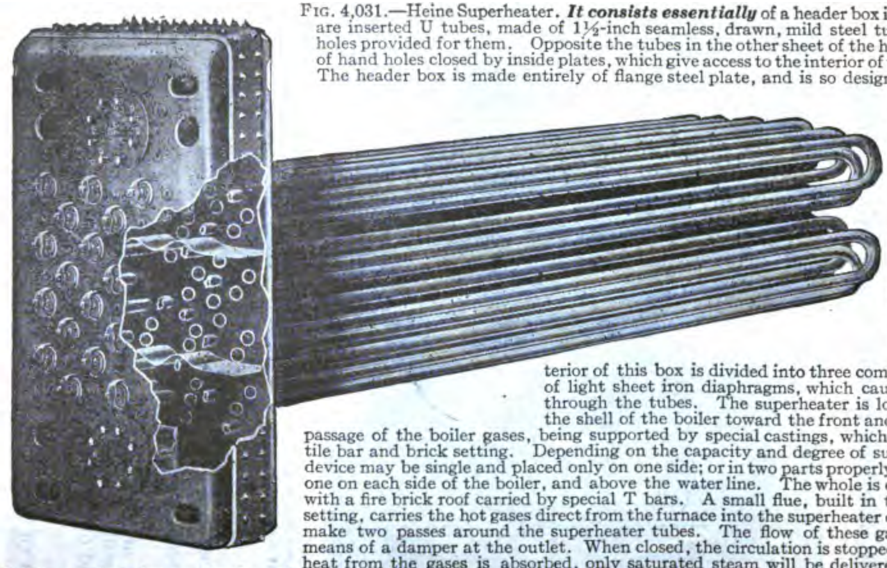


FIG. 4,031.—Heine Superheater. ***It consists essentially*** of a header box into one side of which are inserted U tubes, made of 1½-inch seamless, drawn, mild steel tubing, expanded into holes provided for them. Opposite the tubes in the other sheet of the header box are a series of hand holes closed by inside plates, which give access to the interior of the whole apparatus. The header box is made entirely of flange steel plate, and is so designed that it is entirely machine made. The hollow stay bolts, which hold the two sheets of the box parallel, are of the same size and material as those used in the construction of the boiler proper, and as in the case of the boiler, provide means for introducing the soot blower in order to keep the exterior surfaces of the superheater tubes clean. The interior of this box is divided into three compartments by means of light sheet iron diaphragms, which cause the steam to pass through the tubes. The superheater is located at the side of the shell of the boiler toward the front and just above the last passage of the boiler gases, being supported by special castings, which rest upon the boiler tile bar and brick setting. Depending on the capacity and degree of superheat desired, the device may be single and placed only on one side; or in two parts properly connected together, one on each side of the boiler, and above the water line. The whole is encased in brickwork with a fire brick roof carried by special T bars. A small flue, built in the side walls of the setting, carries the hot gases direct from the furnace into the superheater chamber, where they make two passes around the superheater tubes. The flow of these gases is controlled by means of a damper at the outlet. When closed, the circulation is stopped, and as soon as the heat from the gases is absorbed, only saturated steam will be delivered. By opening the damper, various degrees the flow of gases can be regulated so as to give any desired degree of superheat up to the capacity of the apparatus. Since the hot gases do not come into contact with the damper until after passing through the superheater, there is no danger of overheating it. The usual steam outlet from the boiler proper is connected into the lower opening of the superheater box, the steam passing into the tubes of the lower compartment, thence through these tubes out into the middle compartment, whence they go into the second set of tubes connected with this space and through them issuing finally into the third or top compartment, thence out through the opening there into the general piping system. The effect is to thoroughly mix up the steam so that it is of a uniform temperature. Ordinarily it is not deemed necessary to provide a by-pass so as to enable the superheater to be cut out of service entirely, although such an arrangement can easily be provided if desired.

up, but still within the boiler setting and entirely separated from the main gas passages.

A small quantity of hot gas is conducted from the furnace or combustion chamber through a small duct in the walls, to the superheater chamber where it is brought into intimate contact with the superheating surfaces after discharging into the main passage.

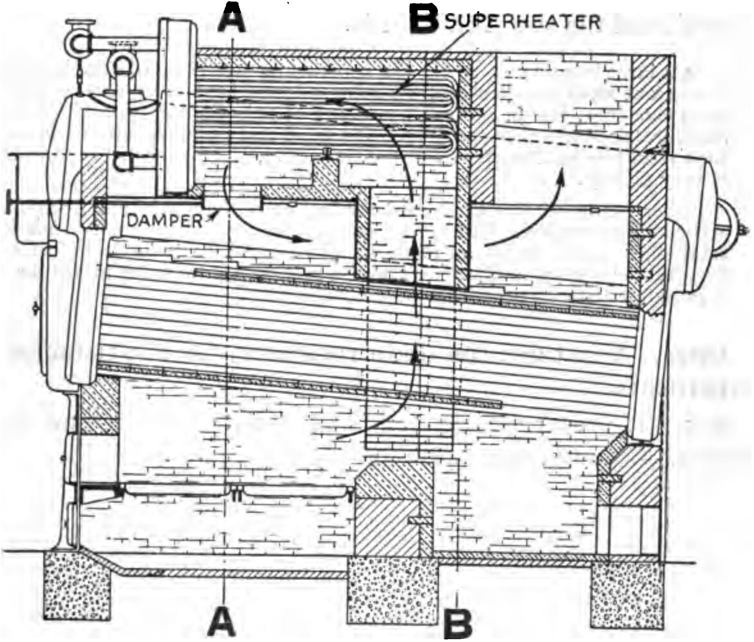


Fig. 4,032.—Heine superheater setting. A small flue in the side walls passes some of the hot gases direct from furnace to superheater chamber, where they make two passes around the superheater tubes. The flow of these gases is controlled by means of a damper at the outlet. When closed the circulation is stopped, and as soon as the heat from the gases is absorbed, only saturated steam will be delivered. By opening the damper various degrees the flow of gases can be regulated so as to give any desired degree of superheat up to the capacity of the apparatus. Since the hot gases do not come into contact with the damper until after passing through the superheater, there is no danger of overheating it. In the Heine bulletin "Superheater Logic" page 30, cross-sectional views on lines **AA** and **BB** are shown, illustrating in further detail the superheater chamber and passage leading thereto.

By manipulating a damper the flow of gas is controlled to suit the degree of superheat desired, and by using thermostatic control a nearer uniform superheating effect may be obtained than in any other way except possibly with the separately fired plan. The steam connection may or may not be arranged to by pass the superheater.

Still another practice, and one for which there are many arguments, is to place the superheater outside the boiler entirely and over a separately fired furnace, passing either the whole or only a portion of the steam through it.

In a large installation where the superheater would be of sufficient size to warrant separate attention, the independently fired superheater will give good economy, but in a plant consisting of only one or two boilers, the superheater would necessarily be quite small and might require more care than would be justified for its operation, as it would be necessary to watch it very closely.

Either gas or oil should be used for fuel since they may be quickly and accurately controlled. Unless so handled it is quite uncertain whether the total efficiency of the steam plant would be increased at all and if such a superheater were placed where it would receive only average attention, it is probable that its use would be unsatisfactory.

Ques. What are the main requisites for a satisfactory superheater?

Ans. 1. proper location; 2, accessibility for cleaning and repairs; 3, safety, and 4, durability.

READY REFERENCE INDEX

A

- Absolute, *temperature*, def., 1,764.
  - value, 1,766.
  - zero, determining, ills., 1,765.
- Absorption of heat, 1,776.
  - rate, 1,776.
- Acetylene, heating valve, 1,852.
- Acid, nitric, fuel analysis, 1,913.
- Air, absolute zero, ills., 1,765.
  - *combustion*, amount required, 1,857.
    - necessary amount, theoretical, calculation, table, 1,861.
  - composition, 1,845.
  - constituents, 1,845.
  - corresponding volume oxygen, finding volume, 1,936.
  - dried peet, analysis, 1,834.
  - *excess*, and CO_2, table, 1,953.
    - *effects*, 1,879.
      - on combustion, 1,856.
    - flue gas, analysis, cooling effects, table, 1,921.
  - furnace, steam boiler materials, ills., 1,987.
  - heating, effects, 1,856.
  - nitrogen effects, 1,856.
  - oxygen, from, 1,845.
  - perfect combustion, actual amount, 1,859.
  - per pound fuel, theoretical amount, computing, 1,859.
  - *required for*, combustion at 32° and 29.92 ins., table, 1,865.
    - combustion, determination, 1,864.
    - various fuels, 1,858.
  - *supply*, fuel gases, non-mixing, effects, 1,878.
    - pre-heating effects, 1,883.
  - volumetric analysis, 1,845.
  - weight analysis, 1,845.
- Alloy, cast iron, steam boiler materials, def., 1,993.
  - steels, steam boiler materials, def., 1,993.
- Almy series parallel pipe boiler, ills., 2,095, 2,115.
- Aluminum steel, steam boiler material, use, 2,004.
- American coals, classification, 1,829.
- Analysis of, air, 1,845.
  - air dried peet, 1,834.
  - candle flame, diag., 1,846.
  - coke, 1,833.
  - flue gas, 1,919–1,938.
  - *fuel*, 1,887–1,918.
    - liquid, 1,917.
  - proximate, see Proximate analysis.
  - ultimate, see Ultimate analysis.
- Analytical balance, Gaertner, ills., 1,893.
  - weights, Eimer & Amend, ills., 1,894.
- Andrews vertical tubular steam heating boiler, ills., 2,136.
- Angle, bar, steam boiler construction, ills., 2,222.
  - corner, ills., 2,217.
  - stays, steel, 2,214.
- Anthracite coal, des., 1,825.
  - semi-, des., 1,825.
  - sizes, 1,831.
- Apparatus, Eliot, flue gas analysis, ills., 1,934.
  - fuel analysis, 1913.
  - necessary for fuel testing, 1,888.
  - *Orsat*, four pipette, ills., 1,932.
    - chemical reagents used, 1,931.
    - flue gas analysis, care of, 1,929.
- Area, gas passage, steam boiler, 1,977.
  - *hand hole(s)*, plate, calc., 2,229.
    - table, 2,228.
  - head to be stayed, des., ills., 2,198–2,201.
  - *man hole*, table, 2,228.
    - plate, 2,229.
- Ashes, analysis, 1,823, 1,915.
  - combustion, constituents, 1,883, 1,886.
  - def., 1,884.
  - determination, fuel analysis, 1,915.
  - *fuel analysis*, 1,892, 1,904.
    - testing for, 1,898.
  - iron oxide, effects of, in, 1,886.
- *A. S. M. E.*, *method of* determining carbon, hydrogen and nitrogen, fuel analysis, 1,902, 1,903.
    - obtaining average flue gas sample, 1,923.
  - riveted joints, ***Boiler Code***, 2,176–2,188, 2,191.
  - testing steam boiler material code, 2,008.
- Asphalt, des., 1,839.

Atmospheric pressure at sea level, 1,790.
Automatic, control, steam heating boiler, 2,152.
  flue gas, collector, Hays, 1,924.
  testing machine, steam boiler material, Olsen, ills., 2,010.
Automobile boiler, Ofeldt, ills., 2,088.
  Stanley, ills., 1,965.
  various, ills., 1,969.
Auxiliary, apparatus, 1,923.

B

Babcock & Wilcox, cross box construction, ills., 2,248.
  marine transverse drum, boiler construction, ills., 2,246.
  sectional, headers, steam boiler cons., ills., 2,254.
    horizontal water tube boiler, ills., 2,080.
Bacharach pocket CO_2 recorder, 1,937, 1,938.
Back rivet pitch, 2,170, 2,171.
Bagasse, des., 1,837.
  heating value, 1,837.
Balance, analytical, Gaertner, ills., 1,843.
  weights, fuel analysis, analytical, Eimer & Amend, ills., 1,894.
Bar, crown, steam boiler construction, 2,214.
  steam boiler construction, angle, ills., 2,222.
Barrel calorimeter, des., 1,811, 1,812.
Base, *steam heating boiler*, International, ills., 2,144, 2,145.
  square, National, parts, ills., 2,132.
Badenhausen water tube boiler, ills., 2,033.
Bell mortar, fuel analysis, ills., 1,904.
Bending, cold, testing steam boiler materials, diag., 2,019.
  stress, def., 2,006.
Bent tube(s) water tube boiler, objection, 2,089.
  Seabury, ills., 2,083.
  Stirling, ills., 2,084.
  various forms, ills., 2,082.
Benzole, heating value, 1,852.
Berry vertical fire tube boiler, ills., 2,108.
Bessemer, converter, ills., 1,991.
  gas, steam heating boiler, ills., 2,133.
  pig iron, def., 1,993.
  process, steel production, 1,991-1,993.
Bigelow-Hornsby multi-drum water tube boiler, ills., 2,093.
Bigelow upright shell boiler, ills., 2,041.
Bituminous, def., 1,825.
  coal, combustion chamber, proportions, 1,879.
  des., 1,826.
  size, des., 1,826.
  semi-, eastern states, 1,831.
    western states, 1,831.
Block coal, des., 1,827.
  particles in smoke, 1,875.
Block coal,—*Continued*
  smoke, indication, 1,877.
Blakeley water tube boiler, ills., 2,057.
Blast tank, laboratory, Clayton & Lambert, ills., 1,900.
Blow pipe, combustion, ills., 1,860.
  operation, 1,860.
  parts, 1,860.
  using, instructions, 1,860.
Boiler(s), apparatus, auxiliary, 1,980.
  automobile, Stanley, ills., 1,965.
    various, ills., 1,969.
  baffled, draught, ills., 2,067.
  bolts, 2,202.
  braces, 2,202.
  breeches flue(s), 2,037.
    Galloway, ills., 2,038.
    Lancashire, des., 2,037.
  cast steel, carbon, 1,990.
  characteristics, 1,973–1984.
    air space ratio, 1,977.
    circulation, 1,978.
    gas passages, 1,977.
    grate dimensions, 1,975.
    heat transmission, 1,976.
    heating surface, 1,973–1,977, 1,980.
    liberating surface, 1,978, 1,979.
    position of boilers, 1,984.
    priming, 1,980.
    steam space, 1,978, 1,979.
    various kinds of boilers, 1,981–1,984.
    water, height of, ills., 1,980.
      space, arrangement, 1,978.
  circulation experiment, ills., 1,802.
  classification, 1,955–1,927.
    externally fired, 1,971.
    furnace arrangements, various, ills., 1,968.
    internally fired, 1,971
    shell, various, ills., 1,956.
    steam generator, diff., ills., 1,971.
    vertical, various, ills., 1,958.
    water tube, various, ills., 1,960, 1,962.
  Clyde, ills., 2,057.
  Code, A.S.M.E., braced and stayed surfaces, 2,201.
  coil, Monitor, ills., 2,144.
  combined shell and water tube, ills., 2,124–2,126.
  Cornish, des., 2,033.
    dimensions, 2,035.
    Lancashire, diff., 1,970.
    per cent. used, 2,112.
  crown sheet, Reynolds, ills., 2,106.
  coverings, 2,006.
  difference between generator and boiler, 1,971, 1,972.
  direct draught, ills., 2,067.
  dome, ills., 2,232.
  double tube, 1,967.
  down draught, ills., 2,070, 2,119, 2,124, 2,126.
  draught, ills., 2,067, 2,070.
  drop tube, Field, ills., 2,045.
    single, ills., 1,958.

Boiler(s),—*Continued*
- duty, 1,973.
- *elementary,* parallel connection, ills., 1,804.
  - series connection, ills., 1,804.
- elephant, per cent used, 2,112.
- evaporation, rates, 1,977.
- expansion provision, 1,772.
- *externally fired,* 1,971, 1,984.
  - per cent used, 2,112.
- Fairbain, advantage of, 2,119.
- *Field tube,* 1,967.
  - operation, 1,967.
  - Ward, ills., 2,072.
- fire box, 1 970.
- *fire tube(s),* 2,099–2,117.
  - *combined,* Fitzgibbons, ills., 2,107.
    - shell, ills., 2124–2126.
  - crown sheet, Reynolds, ills., 2106.
  - duplex and triplex, des., 2,099.
  - internal fire box, vertical, 2,102.
  - horizontal, vertically set, 2,101.
  - radial, vertical, 2,105.
  - *return, horizontal,* duplex, ills., 2,100.
    - triplex, ills., 2,101.
    - object, 2,106.
    - vertical, Webber, ills., 2,107.
  - single flue, ills., 2,112.
  - tri-pass, extended shell, object, 2,110.
  - two-pass, Casey-Hedges, ills., 2,110,
  - *vertical,* Berry, ills., 2,108.
    - Reynolds, ills., 2,105.
    - setting, ills., 2,102.
  - *water tube,* diff., 1,965.
    - Hawkes, 2,121.
    - Silsby, ills., 2,125.
- *flue and fire tube,* Burnham, ills., 2,114.
- *flue,* and tubular, 1,964.
  - disadvantage, 1,964.
  - *Galloway,* breeches and flues, cons., 2,035, ills., 2,038.
  - tube, diff., ills., 1,963.
  - Western river type, Rees, 2,056.
- fuel economy, conditions, 2,031.
- *furnace(s),* arrangements, ills., 1,968.
  - classification, 1,955–1,959.
  - internal, external, comparison, 1,984.
  - shape, classification, 1,959.
- Galloway, des., 2,033.
- Graham, steam heating boiler, ills., 2,148.
  - water tube boiler, ills., 2,077.
- Graham, ills., 2,077, 2,148.
- Gurney, ills., 2,060.
- Gansaulus', classification, 1,959.
- *gas passage,* area, 1,977.
  - arrangement, 1,977.
  - size, 1,977.
- generator and boiler, diff., 1,972.
- *grate,* dimensions, 1,974.
  - function, 1,974.
  - surface, 2,113.
  - various proportions, diag., 1,976.
- *head(er),* hand hole plate, ills., 2,253.
  - ills., 2,250.

Boiler(s), *head(er)*,—*Continued*
  - staying, ills., 2,201.
- hard steel, carbon, percentage, 1,990.
- heat absorbing, class, 1,957.
- *heating surface,* classification, 1,955.
  - essential qualities, 1,973.
  - extensiveness, 1,974.
  - form, 1,974.
  - tubular, characteristic, diag., 1,964.
- heat transmission, measurement, 1,976.
- *horizontal,* openings, ills., 2,237.
  - shell, steam generation, 1,982.
  - tube, ills., 1,958.
  - vertical, steam, difference, 1,982, ills., 1,983.
- insulators, 2,006.
- *internally fired,* 1,971, 1,984.
  - Fairbain, 2,119.
- iron, use, 1,974.
- *Lancashire,* ills., 2,035.
  - breeches, fluid, des., 2,037.
  - dimensions, 2,038.
  - disadvantages, 2,037.
- *liberating surface,* 1,978.
  - classification, 1,957.
  - insufficient, results,, 1,979.
- *locomotive,* 2,045.
  - class, 1,963.
  - horse power, 2,113.
  - per cent used, 2,112.
- *marine,* class, 1,963.
  - Clyde and Scotch, difference, 2,054.
  - des., ills., 2,047.
  - horse power, 2,113.
  - leg, ills., 2,054.
  - over discharge, Mosher, ills., 2,249.
  - position of, 1,984.
  - under discharge, Yarrow, ills., 2,249.
  - vertical, through tube, ills., 2,048.
- mixed types, class., 1,963.
- modern high pressure Scotch, ills., 2,050.
- modified Manning const., ills., 1,958.
- moisture, amount, 1,819.
- multi-tube, ills., Manning, 1,958.
- non-sectional, ills., 2,067, 1,967, 2,067.
- one furnace, ills., 2,052.
- openings, classification, 2,225.
- *pipe,* 2,070, 2,117.
  - features, 2,073.
  - use, 2,074.
  - Taylor, ills., 2,116.
  - use, 2,074.
- *plate,* silicon, effect, 2,005.
  - marine requirements, 2,156.
- *porcupine,* 1,970.
  - tubes in, 1,972.
- position, effect, 1,984.
- pressure, classification, 1,959.
- primary, 1,980.
- rapid circulation, desirability, des., diag., 1,978.
- return tube, features, 2,056.
- *Scotch,* Clyde, diff., 1,970.
  - features, 2,048.

Boiler(s), ***Scotch—Continued***
    - form, 2,054.
    - modern high pressure, ills., 2,050.
- *sectional*, 1,967.
    - series pipe, ills., 2,077.
    - used in various countries, 2,112.
- service, classification, 1,955.
- *setting*, Lancashire, ills., 2,037.
    - materials used in, 1,985.
- *shell*, 2,023.
    - classes, 2,023.
    - *Clyde*, Marine Iron Works, ills., 2,052.
        - removable, ills., 2,051.
    - *Cornish*, ills., 2,034.
        - parts, 2,034.
    - development, 2,025.
    - *elephant*, ills., 2,029.
    - *flue*, tube, difference, 2,025.
        - Galloway, ills., 2,035, 2,038, 2,039.
        - western river type, Rees, ills., 2,056.
    - *horizontal return tubular*, ills., 2,026.
        - des., 2,027.
    - internaliy fired, 2,033.
    - *Lancashire*, breeches flued, des., 2,037.
        - des., 2,035.
        - dimensions, 2,038.
        - disadvantages, 2,037.
        - without breeches, ills., 2,036.
    - large, disadvantage, diag., 1,981.
    - *locomotive*, 2,045.
        - differences, 2,046.
        - wagon top, cons., 2,046.
        - semi-portable, ills., 2,046.
    - *marine*, des., ills., 2,047.
        - locomotive type, Rees, ills., 2,055.
        - Marine Iron Works, special, ills., 2,053.
        - leg, ills., 2,054.
    - plain cylinder, ills., 2,027.
    - return tube, features, 2,056.
    - *Scotch*, features, 2,048.
        - form, 2,054.
        - modern high pressure, ills., 2,050.
        - parts, 2,049.
        - single furnace, ills., 2 051.
    - service classification, 2,023.
    - shape, classification, 1,959.
    - sheets, des., 2,025.
    - single return flue, ills., 2,028.
    - *submerged tube*, 1,958, 2,043.
        - Marine Iron Works, ills., 2.049.
    - *Trevithick*, dimensions, 2,034.
        - ills., 2,034.
    - tube flue, diff., 2,025.
    - *tubular*, three-pass, adv., 2,031.
        - horizontal return, ills., 2,032.
        - three-pass, ills., 2,031.
    - *upright*, Bigelow, ills., 2,041.
        - dry pipe, Graham, ills., 2,044.
        - evolution, diag., 2,040.
        - submerged tube, ills., 2,042.

Boiler(s), ***upright,—Continued***
        - through tube, ills., 2,048.
        - types, 2,041.
    - various, ills., 1,956.
    - wagon, Watts', ills., 2,024.
    - *water*, level, proper, 2,044.
        - pockets, Petrie's, ills.. 2,039.
    - *water tube*, 2,121.
        - Fox, ills., 2,122.
        - Harrisburg, ills., 2,123.
        - sensitiveness, diag., 1,982.
        - use, 2,121.
        - Western river, ills., 2,030.
- single tube, 1,967.
- soft steel, carbon, percentage, 1,990.
- steam formation, 1,799.
- steam space, 1,978.
    - *Clyde*, modified, 2,109.
        - type, Murray, ills., 2,109.
        - single flue, ills., 2,109.
    - internal fire box, vertically extended, 2,102.
    - Kingsford, ills., 2,113.
    - Lyons, combined, adv., 2,120.
    - Smith-Manning, des., 2,104.
    - tube feature, class., 1,957.
- steam generator, ills., 1,971.
- steel, carbon, percentage, 1,990.
    - rust, effects, 1,990.
- superheater, flooding, object, 2,259.
- transfer of heat, method, 1,973.
- Trevithick, des., 2,033.
- tubes, see Tubes.
    - *vertical*, steam generating, 1,982.
        - through tube, ills., 1,958, 1,967.
        - water, 1,790.
    - water, fire, diff., 2,023.
- tubular return, 1,970.
- ***U. S. Marine rules***, manholes, hand holes, 2,232.
- *vertical*, non-sectional, ills., 2,081.
    - openings, ills., 2,237.
    - per cent used, 2,112.
    - various, ills., 1,950.
    - submerged tube, ills., 2,042.
    - through tubes, various, ills., 1,958.
- *water*, circulating, inclined tube method, ills., 1,803.
    - grate, ills., 2,061.
    - height, diag., 1,980.
    - pockets, Petrie's, ills., 2,039.
    - space, arrangement, 1,978.
    - special, classification, 2,099.
- *water tube*, 2,117.
    - advantages, 1,981.
    - automobile, Ofeldt, ills., 2,088.
    - Badenhausen, ills., 2,086.
    - *bent*, objection, 2,089.
        - Seabury, ills., 2,083.
        - Stirling, ills., 2,084.
    - Blakeley, ills., 2,057.
    - *circulation*, directed flow, ills., 2065.
        - feature classification, 2,059.
        - ills., 1,803.
        - over discharge, ills., 2,085.

Boiler(s), *water tube, circulation,—Con.*
    under discharge, ills., 2,065.
  closed, 2,089.
  combustion feature classification, 2,060.
  combustion principles, ills., 2,069.
  curved, 2,080.
  def., 2,057.
  down flow, circulation, ills., 2,064.
    sectional, Parker, diag., 2,096.
    single ended, Parker, types, ills., 2,097.
  draught, down, ills., 2,070.
  elementary, des., 2,061, ills., 2,062.
    operation, 2,062.
  field, Ward, ills., 2,072.
  Graham, ills., 2,144.
  Gurney's, ills., 2,060.
  heating surface classification, 2,058, 2,059.
  James', ills., 2,061.
  load effects, 2,057.
  multi-drum, Bigelow-Hornsby, ills., 2,093.
    Connelly, ills., 2,094.
  non-sectional, advantages, 2,066.
    des., 2,064.
    elementary, longitudinal drum, ills., 2,061.
    horizontal, Casey-Hedges, ills., 2,078.
    Keeler, ills., 2,078.
    water tube,
    vertical, Wicks, ills., 2,081.
  operation, 2,062.
  parallel, arrangement, accessibility, 2,067, ills., 2,068.
    connection, ills., 2,059.
    sectional, elementary, ills., 2,068.
  parts, 2,060.
    ills., 2,060–2,062.
  pipe, Almy, ills., 2,115.
  per cent used, 2,112.
  porcupine, 2,089.
    class., 2,090.
    Niclausse, ills., 2,092.
    Racine, ills., 2,091.
    Shipman, ills., 2,090.
  Roberts, cons., ills., 2,171–2,076.
  sectional, horizontal, Babcock & Wilcox, ills., 2,080.
    parts, 2,066.
  sensitiveness, ills., 1,982.
  series, connection, ills., 2,058.
    parallel, 2,091.
    sectional, ills., 2,068.
  special, 2,117–2,126.
  tube(s), grouping classification, 2,058.
    bent, various forms, ills., 2,082.
  transverse drum, ills., 2,250.
  triple tube, over discharge, Mosher marine, ills., 2,087.
  types, 2,057.
  up flow, circulation, ills., 2,063.

Boiler(s), *water tube, up flow,—Con.*
    down flow, 2,093.
    Vogt, ills., 2,250.
    water, grate, ills., 2,079.
      level, 1,980.
Boiler construction, 2,155–2,262.
  angle, bar, ills., 2,222.
    corner, ills., 2,217.
  bolt, stay, tap thread, 2,205.
  brass, gauges used, 1,985.
  brick, specifications, 1,985.
  bursting pressure, des., diag., 2,162.
  cast iron, use, 2,000.
  copper, smelting methods, 1,985.
  cross box, Babcock & Wilcox, 2,248.
  crown bar, 2,214.
  dome, tracing, diagonal, ills., 2,233.
    proportions, 2,234.
  drum, end, Union Iron Works, ills., 2,247.
    longitudinal header, Edge Moor, ills., 2,246.
    marine transverse, Babcock & Wilcox, ills., 2,246.
    class, 2,244.
    steam and water, Vogt, ills., 2,251.
  Edge Moor, ills., 2,253.
  factor of safety, 2,163.
  fire door, des., ills., 2,242–2,243.
  flat surfaces, reinforcement, 2,201.
  gasket, use, 2,230.
  hand hole, area, table, 2,228.
    des., ills., 2,226.
    fittings, ills., 2,255.
    plate, area, calc., 2,229.
      Union Iron Works, parts, ills., 2,256.
  header, 2,251.
    classes, des., ills., 2,192.
    Edge Moor, ills., 2,255.
    sectional, Babcock & Wilcox, ills., 2,254.
    stayed area, des., ills., 2,198–2,201.
    staying, ills., 2,215.
  heater, feed water, 2,256.
  joint(s), butt, 2,179, 2,181, 2,182, 2,184.
    butt, straps, equal, ills., 2,186.
      ills., 2,169.
    circumferential, ills., 2,191.
    efficiency, diag., 2,160.
    lap, butt, diff., ills., 2,167, 2,168.
      ills., 2,169, 2,177, 2,178.
      single, 2,173.
    riveted, efficiency, 2,171.
    pull, effects, diag., 2,170.
    riveted, strength, 2,160.
      U. S. Marine Rules, 2,189–2,190.
      Wicks, table, 2,188.
  ligament, efficiency, diags., 2,196.
  malleable iron, use, 2,000.
  man hole, area, table, 2,228.
    cover, swinging, Cahill, ills., 2,231.
    des., ills., 2,226.
    Eclipse, ills., 2,227.
    frame, riveting, ills., 2,231.
    plate, area, calc., 2,229.

Boiler construction, *man hole*,—*Continued*

  - reinforcement ring, ills., 2,230.
- manifold, 2,251.
- parts, 1,985.
- pipe threads, number, minimum, 2,235.
- plate, 2,156.
- radial T bars, ills., 2,221.
- reinforcements, types, 2,202.
- *rivet*(*s*), fracture between, ills., 2,175.
  - pitch, 2170, ills., 2,171.
- riveted joints, calc., 2,172.
- rivets, split and double shear, ills., 2,175.
- rules, 2,155.
- seam, element, ills., 2,173.
- shear, single, double, diff., 2,170.
- *shell*, 2,157.
  - course, 2,159.
  - strength, calc., 2,159.
  - *thickness*, 2,165.
    - ills., 2,166.
  - total pressure, diag., 2,158.
- side plates, ills., 2,216.
- sling straps, ills., 2,216.
- stay angle, steel, 2,214.
- *stay bolt*, screwed, maximum, pitch, 2,219.
  - tap, ills., 2,203.
- *stay*(*s*), breaks, 2,207.
  - crow foot, des., 2,213, ills., 2,212.
  - diagonal, types, ills., 2,210.
  - fastening, methods, ills., 2,218.
  - *gusset*, des., ills., 2,211.
    - stress, 2,212.
  - hollow, ills., 2,205.
  - jaw, des., ills., 2,213.
  - palm, des., 2,212, ills., 2,213.
  - radial, des., ills., 2,217.
  - riveted, des., ills., 2,205.
  - rod, des., ills., 2,208.
  - *screwed*, diameter, 2,205.
    - drilled holes, object, 2,206.
    - flaws, des., ills., 2,206.
  - socket, des., ills., 2,207.
  - stress, minimum, 2,221.
  - *tube*, 2,209.
    - ends, ills., 2,209.
    - pitch, 2,211.
- steam drum, Ladd, ills., 2,245.
- steel, application, 1,990.
- *superheater*, 2,256.
  - elements, ills., 2,259.
  - Foster, ills., 2,257, 2,258, 2,259.
  - Heine, ills., 2,260, 2,261.
  - location, 2,258.
- thread stripping, prevention, 2,204.
- *tube*(*s*), 2,238.
  - *expander*, segment, Prosser, ills., 2,240.
    - roller, ills., 2,240.
  - fastening, 2,241.
    - des., ills., 2,193–2,198.
- turnbuckle, ills., 2,209.
- working pressure, des., 2,163, 2,164.

Boiler(,) heating, 2,127–2,154.

- automatic control, 2,152.
- *base*, International, ills., 2,145.
  - square, National, parts, ills., 2,132.

Boiler(,) *heating*,—*Continued*

- capacity, table, 2,151.
- coil, Monitor, ills., 2,144.
- combination, rate, 2,131.
- construction details, 2,143–2,152.
- drop tube, Gorton, ills., 2,141.
- fire pot, National, ills., 2,154.
- *gas*, burner, ills., 2,133.
  - travel, diag., 2,134.
- *heating surface*, 2,128.
  - efficiency, diag., 2,135.
  - inadequate, effect, ills., 2,130.
- *horizontal*, assembling, ills., 2,142–2,143.
  - Capitol, ills., 2,139.
  - circulation, Ideal, ills., 2,147.
  - Graham home made water tube, ills., 2,148.
- International, parts, ills., 2,131.
- long pass, short pass, characteristics, ills., 2,136.
- Mayer, parts, ills., 2,138.
- not cleaning, result, ills., 2,140.
- performance, 2,133.
- "points," 2,133.
- proportions, 2,133.
- push nipple, ills., 2,137.
- section, National, ills., 2,153.
- sectional, Gurney, ills., 2,149, 2,150.
- *steam dome*, 2,152.
  - International, ills., 2,151.
- syphon steam regulator, Ideal, ills., 2,152.
- underfeed, Williamson, ills., 2,137.
- *vertical*, round, ills., 2,128.
  - tubular, Andrews, ills., 2,136.
- water back, Gilt edge, ills., 2,139.

Boiler material(s), 1,985–2,022.

- *alloy*, cast iron, def., 1,993.
  - steels, def., 1,993.
- *Bessemer*, process, ills., 1,991.
  - pig iron, def., 1,993.
  - steel, def., 1,993.
- boiler, plate, silicon, effect, 2,005.
- brass, physical properties, 1,997.
- *bricks*, expansion, 2,005.
  - melting points, 2,006.
  - weight 2,005.
- brittle, def., 1,995.
- *cast iron*, 1,987.
  - def., 1,993.
  - physical properties, 1,997.
- cast steel, def., 1,993.
- charcoal hearth cast iron, def., 1,993.
- cold short, def., 1,995.
- converted steel, def., 1,993.
- copper, physical properties, 1,997.
- crucible steel, def., 1,993.
- ductile, def., 1,995.
- elastic limit, def., 1,995.
- fusible, def., 1,995.
- grey cast iron, def., 1,993.
- *hardness*, def., 1,996.
  - testing, Brinnell method, 1,998.
- homogeneous, def., 1,996.
- hot short, def., 1,996.

Boiler material(s,)—*Continued*
- *malleable*, castings, def., 1,994.
  - producing methods, 1,988.
- melting point of solids, def., 1,996.
- open hearth steel, def., 1,994.
- pig iron, def., 1,994.
- *puddled*, iron, def., 1,994.
  - steel, def., 1,994.
- refined cast iron, def., 1,994.
- resilience, def., 1,996.
- sheer steel, def., 1,994.
- specific gravity, def., 1,996.
- *steel*, aluminum, use, 2,004.
  - carbon, percentage, 2,002.
  - castings, def., 1,994.
  - def., 1,994.
  - manganese, use, 2,004.
  - nickel, use, 2,004.
  - phosphorus, use, 2,003.
  - physical properties, 2,001.
  - *production*, Bessemer process, 1,991.
    - open hearth process, 1,992.
  - sulphur, use, 2,004.
- strength, def., 1,996.
- tensity, def., 1,996.
- tough, def., 1,996.
- used, 1,985.
- washed metal, def., 1,994.
- weldable, def., 1,996.
- weld iron, def., 1,994.
- *white*, cast iron, def., 1,994.
  - pig iron, def., 1,994.
- *wrought iron*, def., 1,988, 1,994.
  - *puddling*, furnace, ills., 1,989.
    - process, 1,988.

Boiler materials(,) testing, 1,997–2,022.
- ***A.S.M.E. Boiler Code***, 2,008.
- bending stress, def., 2,006.
- casting, specimen, ills., 2,021.
- *cold bending*, diag., 2,011.
  - test, 2,020.
- *compression*, 2,007.
  - diag., 2,013, des., 2,015.
- deflection instrument, Olsen, ills., 2,007.
- deformation, 2,007.
- elastic limit, Malyshoff method, diag., 2,002.
- factor of safety, 2,007.
- flattening test, diag., 2,019.
- force, 2,007.
- *hardness*, ills., 2,018.
  - test, 2,020.
- homogenity test, ills., 2,020, des., 2,021.
- oad, 2,007.
- *machine*, automatic, Olsen, ills., 2,010.
  - Olsen, four-screw, ills., 1,999.
- micrometer, ills., 2,005.
- *modulus* of elasticity, 2,009.
  - of rupture, 2,009.
- object, 2,006.
- Olsen micrometer extensometer, ills., 2,002–2,004.
- permanent set, 2,009.
- resilience, 2,011.
- Riehle machine, ills., 2,015.

Boiler materials(,)—*Continued*
- scleroscope, 1,997, 1,998.
- shear, 2,011.
- shearing test, 2,017.
- single, double shear, ills., 2,016.
- specimen holder, Riehle, ills., 2,011.
- standard specimen, diag., 2,008.
- strain, 2,011.
- stress, 2,011.
- *tensile*, diag., 2,012.
  - specimen, ills., 2,012.
- tension, 2,014.
- tortional test, des., ills., 2,017.
- traverse, ills., 2,014, des., 2,016.
- universal machine, tortion attachment, Olsen, ills., 2,001.
- weight beam, Riehle, ills., 2,009.
- yield point, 2,013.

Boiling water, circulation, ills., 1,800.
- importance, ills., 1,802.
- free circulation, importance, 1,801.
- higher temperature of steam, causes, 1,792.
- *pot*, action in, 1,779.
  - inner bend in, effect, ills., 1,801.
- U tube, circulation, 1,801.

Bolt(s), stay, boiler, 2,202.
- boiler construction, ills., 2,202, 2,203.
- tap, thread, 2,205.

Brace, boiler, 2,202.

Bracing, dome, steam boiler construction, diagonal, ills., 2,233.

Brass gauges used, 1,986.
- materials, physical properties, 1,997.

Braun hand power coal grinder, fuel analysis, ills., 1,901.

Breaking stay bolts, steam boiler construction, 2,207.

Breeches, flue boiler, 2,037.
- Galloway boiler, ills., 2,038.

Bricks, compressive strength, 2,006.
- boiler materials and specifications, 1,986.
- expansion, 2,005.
- fire, furnace, selection, consideration, 1,884.
- melting points, 2,006.
- weight, 2,005.

Brinnell method of testing, hardness of boiler materials, 1,998.

Briquetted peat, des., 1,834.

British Thermal Unit, def., 1,756.

Brown platinum-rhodium thermo-couples, ills., 1,768.

Bunsen, *burner*, operation, 1,853.
  - parts, ills., 1,853.
- fall pump, flue gas analysis ills., 1,927.

Bureau of Mines, *determining*, carbon, fuel analysis, 1,902.
  - hydrogen, 1,902.
  - nitrogen, 1,903.
  - *method of*, obtaining average flue gas sample, 1,924.
    - sealing shipping cams, ills., 1,892.

Burnham flue and fire tube boiler, ills., 2,114.

Bursting pressure, steam boiler construction, diag., des., 2,162.
Butt joint(s), steam boiler construction, ills., 2,169, 2,179, 2,181, 2,182, 2,184, 2196.

C

Calorimeter, barrel, des., 1,811, 1,812.
  combustion, double valve type, Emerson, ills., 1,870.
  connections, wrong, diag., 1,817.
  Carpenter, ills., 1,916.
    operation, 1,916.
    principles, 1,916.
  fuse wire, correction, 1,912.
  heat radiation, correction, 1,912.
  ignition wiring, methods, Emerson, ills., 1,908.
  Mahler, ills., 1,906.
  radiation correction, Pfaundler's method, 1,912.
  readings, erroneous, ills., 1,817.
  sampling nozzle, 1,820.
    Stott and Pigott, ills., 1,818.
  Sarco, ills., 1,907.
  Scientia, ills., 1,915.
  separating, des., 1,815.
    error, percentage, 1,811.
    operation, 1,816.
  sulphur correction, fuel analysis, 1,914.
  test, des., 1,909.
    fuel analysis, heat of, combustion, 1,905.
  Thompson, ills, 1,918.
  throttling, compact, ills., 1,819.
    Ellison, construction, 1,813.
      ills., 1,813.
      operation, 1,813.
    error, percentage, 1,811.
    ills., 1,814.
    ice to steam, ills., origin plate, 1,820.
  types, 1,811.
  uses, 1,811.
  vacuum walled jacket, Emerson, ills., 1,909.
  water equivalent, 1,914.
    methods of obtaining, 1,914.
Calorific values combustible gases, 1,871.
Can, shipping, sealing method, ***U. S. Bureau of Mines***, ills., 1,892.
Candle flame, analysis, diag., 1,846, 1,874.
Cannel coal, des., 1,827.
Capacity, flue gas collectors, 1,925.
  table steam heating boilers, 2,151.
Capitol horizontal steam heating boiler, ills., 2,139.
Carbon, apparatus for determining, ills., 1,913.
  cast steel, percentage, 1,990.
  des., 1,847.
  dioxide, physical properties, 1,853.
  fixed, 1,823, 1,889, 1,898.

Carbon,—*Continued*
  fuel analysis, ***A.S.M.E.*** method of determining, 1,902.
      Bureau of Mines, method of determining, 1,902.
    hard steel, carbon percentage, 1,990
    hydrogen ratio, coal classification, use, 1,829.
  steel, percentage, 1,990, 2,002.
      steam boiler materials, uses, 2,002
Carpenter calorimeter, 1,916.
Cartridge details, Parr calorimeter, ills., 1,910.
Casey-Hedges non-sectional horizontal water tube boiler, ills., 2,078.
  two pass fire tube boiler, ills., 2,110.
Cast iron, *steam boiler material*, 1,987.
    alloy, def., 1,993.
    charcoal hearth, def., 1,993.
    grey, def., 1,993.
    open hearth process, ills., 1,992.
    physical properties, 1,997.
    refined, def., 1,994.
    use, 2,000.
    white, def., 1,994.
Cast steel, carbon percentage, 1,990.
  def., 1,993.
  malleable, def., 1,994.
  steel, def., 1,994.
Centigrade thermometer scale, 1,763.
Chamber *combustion*, bituminous coal, proportions, 1,879.
    heat storing, effects, 1,879.
    refractory properties, effects, 1,879.
"Change of state," def., 1,781.
  how effected, 1,782.
  temperature, 1,782.
Charcoal hearth cast iron def., 1,993.
Chart(s), CO_2 recorder, Sarco, ills., 1,943.
  smoke, Ringelmann, diag., 1,880.
  Uehling CO_2 recorder, diag., 1,952.
Circulation, features, classification, water tube boiler, 2,059.
  Ideal horizontal steam heating boiler, ills., 2,147.
  in boilers, importance, ills., 1,802.
  of water, in boiling, ills., 1,800.
    in boilers, ills., 1,803.
  rapid, steam boiler desirability, des., diag., 1,978.
  water in boilers, inclined tube method, ills., 1,803.
  water tube boiler(s), directed flow, ills., 2,064, 2,065.
Circumferential joint, steam boiler construction, ills., 2,191.
Clayton & Lambert, laboratory blast torch, ills., 1,900.
Clinkers, cause, 1,883.
  def., 1,885.
Closed, *vessel*, vaporization, effects, 1,779.
    temperature, lowering, effects, 1,799.
  water tube boilers, 2,089.
Clyde, & Scotch marine boilers, difference, 2.054.

- **Clyde,—*Continued.***
  - boiler, Marine Iron Works, ills., 2,052.
  - type, *special boiler*, modified, 2,109.
    - Murray, ills., 2,109.
    - single flue, ills., 2,109.
  - water back, removable, ills., 2,051.
- Coal, age, classification, 1,825.
  - American, classification, 1 829.
  - losses, table, 1,953.
  - *anthracite*, des., 1,825.
    - sizes, 1,831.
  - ash, des., 1,823.
  - *bituminous*, des., 1,826.
    - semi-, des., 1,826.
    - *size*, eastern states, 1,831.
      - western states, 1,831.
  - block, des., 1,827.
  - cannel, des., 1,827.
  - carbon hydrogen ratio, classification, use, 1,829.
  - *chemical*, composition, 1,824.
    - constituents, 1,823.
  - classification, 1,824, 1,825.
  - combustible, total, des., 1,823.
  - *combustion*, air required for, 1,861.
    - characteristics, 1,825.
  - composition of, 1,876.
  - culm, des., 1,828.
  - density, classification, 1,825.
  - fixed carbon, des., 1,823.
  - fuel analysis, heating value, calc., 1,911.
  - gas, comparison, table, 1,843.
  - grinder, fuel analysis, hand power, Braun, ills., 1,901.
  - *heating values*, 1,828.
    - different causes, 1,823.
  - *lignite*, des., 1,824, 1,827.
  - location, 1,823.
  - lumps, 1,830.
  - *oil*, evaporation, comparative, 1,841.
    - fuel value, relative, 1,840.
  - properties of, 1,822.
  - *sample*(*s*), gross, preparing, ills., 1,890-91.
    - Jones, ills., 1,905.
  - sizes, 1,830, 1,831.
- Coal tar, composition, chemical, 1,838.
  - des., 1,838.
  - heating value, 1,838.
  - vs. oil tar, 1,839.
  - testing, 1,889.
  - vegetable origin, evidence, 1,824.
  - *volatile matter*, des., 1,823.
    - percentage curves, 1,872.
  - wood, heating values, comparative, 1,835.
- Cochrane boiler, ills., 1,938.
- Coefficient of, expansion, diag., 1,772.
  - linear expansion, def., 1,772.
- Coke, analysis, 1,833.
  - combustion, air required for, 1,861.
  - des., 1,832.
  - gas retort, production, 1,832.
  - heating value, 1,833.
  - physical properties, 1,832.
- Coil boiler, Monitor, ills., 2,144.
- Cold, bending, test, diag., 2,019, 2,020.
  - effects, 1,755.
  - molecular vibration, influence, 1,755.
  - short, def., 1,995.
  - shut, def., 1,995.
- Collector, *flue gas*, automatic, Hays, 1,924.
    - capacity, 1,925.
    - ills., 1,926.
    - operation, 1,926.
    - over water, objection, 1,925.
    - sample, Hays automatic flue gas collector, 1,924.
- Colored smoke, indication, 1,876.
- Combined fire tube boiler, Fitzgibbons, ills., 2,107.
- Combustible, def., 1,889.
  - *principle*(*s*,) 1,847.
    - variation, 1,847.
  - total, des., 1,823.
- Combustion, actual, resultant, 1,921.
  - *air*, excess, effects, 1,879.
    - heating, effects, 1,856.
    - necessary amount, theoretical, calculated, table, 1,861.
    - *nitrogen*, effects, 1,856.
      - effect, useful, 1,856.
    - supply, pre-heating, effects, 1,883.
  - analysis, ultimate, 1,858.
  - *ashes*, def., 1,884.
    - iron oxide, effects of in, 1,886.
    - principle constituents, 1,885.
  - *blow pipe*, ills., 1,860.
    - operation, 1,860.
    - parts, 1,860.
    - using, instructions, 1,860.
  - calorimeter, double valve type, Emerson, ills., 1,870.
  - candle flame, analysis, diag., 1,846.
  - *carbon*, des., 1,847.
    - dioxide, physical properties, 1,853.
  - *chamber*, bituminous coal, 1,879.
    - heat storing, effects, 1,879.
    - refractory properties, effects, 1,879.
  - character of coal classification, 1,825.
  - *clinker*(*s*), def., 1,885.
    - cause, 1,833.
  - coal, volatile matter, percentage curves, 1,872.
  - *complete*, 1,851, 1,853.
    - ashes, percentage, 1,886.
    - hydro-carbon gases, how obtained, 1,878.
    - oxygen, amount necessary, 1,854.
  - crucibles, various, ills., 1,873.
  - Davy's lamp, experiment with, ills., 1,849.
  - def., ,845.
  - Dulong's formula, 1,864.
  - elements, 1,850.
  - excess air, effects, 1,856.
  - feature classification, water tube boiler, 2,060.
  - *flame*, candle, 1,874.
    - cooling ignition temperature, ills., 1,850.
    - visible, 1,875.

Combustion,—*Continued*
  fuel, def., 1,846.
    dry, heating value, formulæ, 1,864.
    gaseous, heating valve, 1,869.
    gases, air supply, non-mixing, effects, 1,878.
    heating value, available, 1,865.
      determination, 1,862, 1,863.
      high and low, 1,869.
    incombustible matter, 1,885.
    kindling temperature, 1,850.
    smoke causes, 1,877.
    various, air required, 1,858.
  furnace, design, poor, effects, 1,884.
    fire brick, selection, 1,884.
    temperature, calculating, 1,881.
      increasing, 1,883.
  gases, calorfic valves, 1,871.
  heat of, calorimeter, fuel analysis, table, 1,912.
    calorimeter test, 1,905.
  hydro-carbon, acetylene, heating valve, 1,852.
    benzole, heating value, 1,852.
    heating valve, 1,852.
    marsh gas, heating value, 1,852.
    methane, heating value, 1,852.
    olefiant gas, heating value, 1,852.
  hydrogen, des., 1,848.
    density, 1,848.
  ignition point, 1,849.
  imperfect, how indicated, 1,876.
  incomplete, 1,855.
    ills., 1,851.
  kindling point, 1,849.
  perfect, air, actual amount, 1,859.
    invisibility, 1,875.
    products, resultant, 1,920.
    results, 1,853.
  principles, water tube boiler, ills., 2,069.
  proximate analysis, 1,873.
  rates, steam heating boiler, ills., 2,138.
  Ringlemann's readings, plotting, diag., 1,882.
  secondary, causes, 1,861.
  smoke, black, indications, 1,877.
    black particles, 1,875.
    causes, ills., 1,876.
    chart, Ringelmann, diag., 1,880.
    classification, 1,880.
    colored, indication, 1,876.
    density, determining, electrical method, 1,882.
      grading, 1,881.
  heating boiler, rate, 2,131.
  sulphur, des., 1,849.
  supporter of, ills., 1,855, 1,857.
  surface of flame, ills., 1,854.
  ultimate analysis, 1,863.
  throttling, calorimeter, ills., 1,819.
Compression test, 2,007, 2,013, 2,015.
  steam boiler materials, diag.
Compressive strength, bricks, 2,006.
Condensation, causes, 1,799.
Conductivity of heat, in metals, ills., 1,775.
Connelly multi-drum water tube boiler, ills., 2,094.
Cooling, effects due to excess air, table, 1:921.
  of flame below ignition temperature, ills., 1,850.
Copper, smelting methods, 1,986.
  physical properties, 1,997.
Corner angles, steam boiler const., ills., 2,217.
Couple, thermo–, Fox bars, com., ills., 1,769.
Courses, shell, boiler construction, 2,159.
Cover, man hole, steam boiler construction, swinging, Cahill, ills., 2,231.
Coverings, steam boiler, 2,006.
Cornish boiler, des., 2,033.
  dimension, 2,035.
  parts, 2,034.
Cornish, Lancashire steam boiler, diff., 1,970.
CO_2 recorder, air excess, table, 1,953.
  auxiliary boiler room, Uehling, ills., 1,954.
  Bacharach pocket, ills., 1,937.
  chart, sarco, ills., 1,943.
  checking CO_2, 1,914.
  draught gauge, 1,949.
  elementary, operation cycle, 1,944.
  flue gas analysis, Bacharach pocket, manipulation, diag., 1,938.
  fuel losses, table, 1,953.
  gauge, Uehling, ills., 1,954.
  machine, Uehling, ills., 1,952.
  operation, principles, 1,943.
  readings, taken alone, unreliability, 1,939.
  Sarco, 1,948.
    operation, 1,941.
    parts, ills., 1,940.
  Uehling, charts, diag., 1,952.
    important parts, diag., 1,951.
    working principles, diag., 1,950.
  what CO_2 indicates, 1,939.
Critical temperature, diag., 1,781.
Cross box, steam boiler construction, Babcock & Wilcox, ills., 2,248.
Crow foot stay, 2,213, ills., 2,212.
Crown, bar, steam boiler construction, 2,214.
  sheet, Reynolds, boiler, ills., 2,106.
Crucible(s), combustion, various, ills., 1,873.
  steel steam boiler, material, def., 1,993.
Crude oil, des., 1,839.
Crusher plate, fuel analysis, ills., 1,902.
Cube, Leslie, ills., 1,773.
Culm, des., 1,828.
Curved water tube boilers, 2,080.
Curves, volatile matter, coats, percentage, 1,872.
Cycle, operation, cog recorder, 1,944.

D

Davy's safety lamp, cams, 1,847.
  experiment with, ills., 1,849.
  ills., 1,847.
  principles, ills., 1,848.

Deformation test, steam boiler materials, 2,007.
Density, liquid, point, 1,788.
maximum, liquid, 1,788.
volumetric changes, 1,788.
of, coal, classification, 1,825.
hydrogen, 1,848.
smoke, determining, electrical method, 1,882.
grading, 1,881.
Ringelmann scale, ills., 1,881.
Design, furnace, poor, effects, 1,884.
Dessicator, fuel analysis, Scheibler, ills., 1,899.
Diagonal, bracing, steam dome, ills., 2,233.
rivet pitch, 2,170, ills., 2,171.
stay, types, ills., 2,210.
Diameter, screwed stay, 2,205.
Dioxide, carbon, physical properties, 1,853.
Directed flow, water tube boiler, ills., 2,065.
Distillates in coal, 1,876.
Dome steam boiler, bracing, ills., 2,233.
International, ills., 2,151.
proportions, 2,234.
Doors, fire, des., ills., 2,242–2,243.
Down, *draught* steam heating boiler, ills., 2,149.
water tube boiler, ills., 2,070.
flow, water tube boilers, ills., 2,064, 2,070, 2,096, 2,097.
Draught gauge, CO_2 recorders, 1,949.
Drop tube boiler, Field, ills., 2,045.
heating boiler, Gorton, ills., 2,141.
Drum, see boiler(s), *drum*, 2,245.
Dry, fuel, heating value, formulæ, 1,864.
pipe, upright shell boiler, Graham, ills., 2,044.
steam, 1,789.
Drying oven, Gaertner, ills., 1,896.
Ductile, def., 1,995.
Dulong's formula, oil tar, 1,839, 1,864.
Duplex, and triplex fire tube boilers, des., 2,099.
horizontal return fire tube boiler, ills., 2,100.

E

Eastern States bituminous coal, 1,831.
Eclipse manhole construction, ills., 2,227.
Edge Moor, header, ills., 2,255.
longitudinal header drum, boiler construction, ills., 2,246.
steam boiler construction, ills., 2,253.
Eimer & Amend, analytical balance weights, ills., 1,894.
double wall oven, ills., 1,895.
muffle furnace, fuel analysis, ills., 1,896.
reading lens, ills., 1,911.
sulphur photometer, ills., 1,914.
Elastic limit, Malysheff method, determining, diag., 2,002.
steam boiler materials, def., 1,995.
Elasticity, modulus of, 2,009.
Electric, muffle furnace, ills., 1,896.
method of determining smoke density, 1,882.
Elementary, CO_2 recorder, operation cycle, 1,944.
non-sectional water tube boiler, longitudinal drum, ills., 2,066.
parallel sectional water tube boiler, ills., 2,068.
series sectional water tube boiler, ills., 2,068.
steam boiler, parallel connection, ills., 1,804.
series connection, ills., 1,804.
water tube boiler, des., 2,061, ills., 2,062.
Elephant boiler, ills., 2,029.
Eliot apparatus, flue gas analysis, ills., 1,934.
Ellison throttling calorimeter, 1,813.
Emerson, *calorimeter*, ignition wiring, methods, ills., 1,908.
vacuum walled jacket, ills., 1,909.
double valve type calorimeter, ills., 1,870
Energy, row plants receive, 1,822.
Engine, *fire boiler*, fire tube water tube, Silsby, ills., 2,125.
shell water tube, Fox, ills., 2,122.
Equivalent, of heat, mechanical, 1,770.
water, calorimeter, 1,914.
Eschkas method, fuel analysis, 1,900.
Ethelyne, heating valve, 1,852.
Evaporation, *factors of*, 1,803, 1,805, 1,806.
table, 1,807, 1,808.
latent heat, 1,781.
of coal and oil, comparative, 1,841.
rates, steam, boiler, 1,977.
standard, 1,805.
water, fuel, table, 1,844.
Evolution of, horizontal return tubular boiler, ills., 2,026.
upright boiler, diag., 2,040.
Excess air, and Co_2, table, 1,953.
combustion, effects, 1,856.
flue gas analysis, table, 1,921.
Expander, *tube*, roller, ills., 2,240.
segment, Prosser, ills., 2,240.
Expansion, coefficient of, diag., 1,772.
due to heat, 1,771.
advantages, 1,773.
linear, coefficient of, def., 1,772.
liquid, 1,788.
of bricks, 2,005.
provision in boilers, 1,772.
Extended shell tri-pass fire tube boiler, 2,110.
Extension and compression micrometer, Olsen, ills., 2,005.
Extensometer, micrometer, Olsen, 2,002–2,004.
External, *latent heat*, 1,795.
diag., 1,796.
External, *work of fusion*, 1,786.
diag., 1,787.
formula, 1,787.
work of vaporization 1,795.
Externally fired boiler, 1,971, 1,984.

F

Factor(s) of evaporation, 1,805.
how obtained, 1,803.
table, 1,808.
use, 1,807.
Factor of safety, steam boiler, 2,163.
test, steam boiler materials, 2,097.
Fahrenheit, surfusion, 1 785.
thermometer, scale, 1,763.
Fall pump, Bunsen, ills., 1,927.
Feed water heaters, boiler construction, 2,256.
Field drop tube boiler, ills., 2,045, 2,072.
operation, 1,967.
Ward, ills., 2,072.
Fire, box, boiler, 1,970.
bricks, furnace, selection, consideration, 1,884.
doors, steam, des., ills., 2,242–2,243.
engine boiler, fire tube water tube, Silsby, ills., 2,125.
shell, water tube, Fox, ills., 2,121.
pot, steam heating boiler, National, ills., 2,154.
tube and water tube boiler, diff., 1,965.
Fire tube boiler, see Boiler(s) *fire tube.*
Firing, grate shape, boiler characteristics, effect, diag., 1,975.
proper, condition necessary, 1,887.
Fittings, header hand hole, ills., 2,255.
Fitzgibbons combined fire tube boiler, ills., 2,107.
Fixed carbon, des., 1,823.
def., 1,889.
fuel analysis, testing for, 1,898.
Fixed points, thermometer scale, 1,760.
Flame, *candle,* analysis, diag., 1,846.
ills., 1,874.
parts, ills., 1,874.
cooling, ignition temperature, ills., 1,850.
surface, only complete combustion, ills., 1,854.
visible, 1,875.
Flattening test, diag., 2,019.
Flooding superheater, object, 2,259.
results, 2,259.
Flue, *and fire tube boiler,* Burnham, ills., 2,114.
object, 2,114.
and tube, diff., 2,025.
and tubular steam boiler, 1,964.
boiler, disadvantages, 1,964.
Western river type, Rees, ills., 2,056.
Galloway, ills., 2,039.
Flue gas analysis, 1,919–1,938.
basis chemical reaction, 1,928.
CO_2, increased saving due to, 1,920.
CO_2 recorder, Bacharach pocket, ills., 1,937, 1,938.
Eliot apparatus, ills., 1,934.
excess air, cooling effects, table, 1,921.
fall pump, Bunsen, ills., 1,927.
jet pump, Richards, ills., 1.927.

Flue gas analysis,—*Continued*
Orsat apparatus, care of, 1,929.
chemical reagents used, 1,931.
des. 1,932.
four pipette, ills., 1,932.
precision 100 cc. standard, ills., 1,936.
three pipette, connection, ills., 1,930.
pipette, Hempel, ills., 1,933.
precision "Boiler tester," ills., 1,935.
parts, 1,935.
process, des., 1,928.
resultant products perfect combustion, 1,920.
results, 1,919.
sampling tube, location, 1,925.
steam pump, des., 1,928.
Flue gas, collecting over water, objection, 1,925.
collector, automatic, Hays, collecting sample, 1,924. 1,925, 1,926,
precision, ills., 1,923.
pumps, types, 1,926.
sample average, obtaining, A.S.M.E. method, 1,923.
obtaining, ***Bureau of Mines*** method, 1,924.
sample, taking best method, 1,925.
sampling, 1,923.
Flue, shell boiler, Galloway, cons., 2,035.
Foster superheater, elements, ills., 2,259.
ills., 2,257, 2,258.
Four, pipette Orsat apparatus, ills., 1,932.
screw testing machine, Olsen, ills., 1,999.
Foxboro thermo-couple, cons., ills., 1,769.
Fox shell water tube fire engine boiler, ills., 2,122.
Frame, man hole, riveting, ills., 2,231.
Free circulation of water, importance, 1,801.
Freezing, point thermometers, method of determining, ills., 1,761.
water, as it boils, Leslie's experiment, diag., 1,782.
volumetric change, 1,785.
"From and at 212° F," def., 1,805.
Fuel, amount, boiler characteristics, determination, 1,975.
Fuel analysis, 1,887–1,918.
analytical balance, Gaertner, ills., 1,893.
approximate analysis, 1,892.
apparatus required, 1,893.
ultimate difference, 1,889.
ash, 1,892.
analysis, 1898, 1,915.
balance weights, analytical, Eimer & Amend, ills., 1,894.
bell motors, ills., 1,904.
calorimeter, see Calorimeter.
carbon, A.S.M.E., determining, 1,902.
Bureau of Mines, determining, 1,902.
fixed, def., 1,884.
testing for, 1,898.
coal, grinder, hand power, Braun, ills., 1,901.

Fuel analysis, *coal,*—*Continued*
heating value, calc., 1,911.
sample, gross, preparing, ills., 1,890–1,891.
Jones, ills., 1,905.
combustible, def., 1,889.
crusher plate, ills., 1,902.
dessicator, Scheibler, ills., 1,899.
furnace, electric muffle, Eimer & Amend, ills., 1,896.
muffle, Weisnegg's, ills., 1,898.
heating value, see Heating value.
hydrogen, A.S.M.E. and ***Bureau of Mines,*** determining, 1,902.
laboratory, blast torch, Clayton & Lambert, ills., 1,900.
burners, various, ills., 1,897.
lens, reading, Eimer & Amend, ills., 1,911.
liquid, 1,917.
sulphur test, 1,918.
ultimate, 1,917.
moisture, 1,892.
determining, 1,902.
testing, methods, 1,894.
necessity of, 1,887.
nitric acid correction, 1,913.
nitrogen, A.S.M.E. and ***Bureau of Mines,*** determining, 1,903.
oven, double wall, Eimer & Amend, ills., 1,895.
oxygen determination, 1,904.
pellet press, ills., 1,904.
shipping cans, method of sealing, ***U. S. Bureau of Mines,*** ills., 1,892.
sulphur, correction, 1,914.
determining, 1,903.
photometer, Eimer & Amend, ills., 1,914.
testing, 1,899.
Eschbach's method, 1,908.
total carbon determination apparatus, ills., 1,913.
ultimate, analyses, 1,900.
apparatus required, 1,902.
heating value, 1,904.
heat value, determining, objection to, 1,905.
items, considered, 1,901.
proximate, difference, 1,889.
volatile matter, 1,889, 1,895.
Fuel(s), *bagasse,* des., 1,837.
heating value, 1,837.
character, classification, 1,821.
clinker, def., 1,885.
coal, gas, comparison, table, 1,843.
heating values, 1,828.
oil, evaporation, comparative, 1,841.
fuel value, relative, 1,840.
sizes, 1,830.
testing, methods, 1,889.
coke, des., various kinds, 1,825 1,828.
gas retort, production, 1,832.
combustion, see Combustion

Fuel(s), *combustion,*—*Continued*
heating value, available, 1,865.
determining, ultimate analysis, method, 1,863.
incombustible matter, 1,885.
kindling temperature, 1,850.
crude oil, composition, 1,839.
definition, 1,821, 1,846.
dry, heating value, formula, 1,864.
economy condition, steam boiler, 2,031.
gas, amount per H. P. required, 1,844.
coal, comparison, table, 1,843.
liquid fuel, comparison, 1,843.
natural, heating value, 1,843.
gaseous, composition, 1,842.
heating value, 1,869.
gases, air supply, non-mixing, effects, 1,878.
heating value, see Heating value.
liquid, 1,839–1,842.
crude oil, composition, 1,839.
gas fuel, comparison, 1,843.
oil, ***U. S. Navy*** report, 1,841.
petroleum, heating value, 1,840.
losses and CO_2, table, 1,953.
represented by CO_2, 1,950.
oil, advantages, 1,839.
coal, evaporation, comparative, 1,841.
coal, fuel value, relative, 1,840.
U. S. Navy report, 1,841.
peet, 1,833, 1,834.
petroleum, heating value, 1,840.
kinds, 1,839.
sawdust, conditions necessary for, 1,837.
heating value, 1,837.
smoke, causes, 1,877.
state, classification, 1,821.
straw, composition, 1,836.
heating, 1,836.
tan bark, use, 1,836.
wet, proper use, 1,836.
tar, coal, composition, chemical, 1,838.
des., 1,838.
heating value, 1,838.
oil, composition, 1,839.
heating value, 1,839.
testing, apparatus, necessary, 1,888.
use of, knowledge necessary, 1,887.
value of coal and oil, relative, 1,840.
various, air required, 1,858.
water evaporation, tables, 1,844.
wood, kinds of, 1,835.
term, 1,834.
water, effect, 1,835.
Furnace(s), air, steam boiler materials, ills., 1,987.
arrangements, steam boiler, various, ills., 1,968.
classification, steam boiler, 1,955, 1,959.
combustion, temperature, calculating, 1,881.
design, poor, effects, 1,884.
fire brick, selection, consideration, 1,884.

Furnace(s),—*Continued*
electric muffle, Eimer & Amend, ills., 1,896.
muffle, Weisnegg's, ills., 1,898.
open hearth, steel production, ills., 1,992.
puddling, wrought iron, ills., 1,989.
shape classification, 1,959.
internal, external, comparison, 1,984.
temperature, increasing, 1,883.
Fuse wire correction, calorimeter, 1,912.
Fusible, def., 1,995.
Fusion, 1,788.
description, 1,782.
external work, 1,786, 1,787.
formula, 1,787.
heat, latent, def., 1,783.
internal work, 1,786.
formula, 1,786.
latent heat, of, 1,781.
use of, 1,783.
of ice, changes necessary, 1,781.
work of, 1,786.

G

Gaertner, analytical balance, ills., 1,893.
drying oven, fuel analysis, ills., 1,896.
Galloway, boiler, des., 2,038.
boiler showing breeches and Galloway flues, ills., 2,038.
flue, ills., 2,039.
cons., 2,035.
tubes, steam boiler, 1,970.
Galvanic action on steel, effects, 1,990.
Gas(es), and liquid fuels, comparison, 1,843.
burner, steam heating boiler, ills., 2,133.
coal, comparison table, 1,843.
combustion, calorific values, 1,871.
description, 1,781.
flow, Ideal horizontal steam heating boiler, ills., 2,147.
flue analysis, see Flue gas analysis.
Gas, hydro-carbon, complete combustion, how obtained, 1,878.
marsh, heating value, 1,852.
molecular movements, 1,756.
natural, heating value, 1,843.
olefiant, heating, value, 1,852.
passage, steam boiler, area, 1,977.
required per H. P., fuels, amount, 1,844.
retort coke, production, 1,832.
specific heat variation, 1,778.
travel, steam heating boiler, diag., 2,134.
Gaseous fuels, composition, 1,842.
heating value, 1,869.
Gaseous steam, 1,790.
Gases, specific heat, table, 1,778.
Gasket, steam boiler construction, use, 2,230.
Generator, difference between boiler and, ills., 1,971, 1,972.
types, 1,972.
Gilt edge water back, steam heating boiler. ills., 2,139.
Gorton drop tube steam heating boiler, ills., 2,141.
Graham, dry pipe for upright shell boilers, ills., 2,044.
steam heating boiler, ills., 2,148
water tube boiler, ills., 2,148.
Grate dimensions, 1,974.
function, 1,974.
surface, boiler, 2,113.
various proportions, diag., 1,976.
water tube boiler, water, ills., 2,079.
width, boiler characteristics, 1,975.
Gravity, specific, def., 1,996.
Gray, pig iron, def., 1,993.
cast iron, def., 1,993.
Gauge, *CO_2 recorder*, Uehling, lls., 1,954.
draught, CO_2 recorder, 1,949.
Gunsaulus steam boiler classification, 1,959.
Gurney's boiler, ills., 2,060.
down draught steam heating boiler, ills., 2,149.
sectional steam heating boiler, ills., 2,149, 2,150.
Gusset stay, des., ills., 2,211. stress, 2,212.

H

Hand, *hole*, plate, area, calc., 2,229.
fittings, ills., 2,255.
plate, Union Iron Works, parts, ills., 2,256.
table, 2,228.
power coal grinder, Braun, ills., 1,901.
Hard steel, carbon percentage, 1,990.
Hardness, def., 1,996.
testing, Brinnell method, 1,998.
boiler materials, 2,020, ills., 2,018.
Harrisburg shell water tube boiler, ills., 2,123.
Hawkes fire tube, water tube boiler, ills., 2,121.
Hays, automatic flue gas collector, ills., 1,924.
Head, area stayed, des., ills., 2,198–2,201.
Header(s), See Boiler construction, *header(s)*.
Heat, absorption, 1,776.
conductivity, des., 1,774.
in metals, ills., 1,775.
definition, 1,755.
effects, 1,755.
expansion, advantages due to, 1,773.
due to, 1,771.
latent, des., ills., 1,794.
evaporation, 1,781.
external, 1,795.
diag., 1,796.
fusion, 1,781.
internal, 1,794.
heat units, 1,795.
mechanical equivalent, 1,770, 1,771.
molecular vibration, influence, 1,755.
of combustion, fuel analysis, table, 1,912.
of fusion, latent, def., 1,783.
of vaporization, latent, def., 1,791.

Heat,—*Continued*
  radiation of calorimeter, 1,912.
  relative conductivity, table, 1,775.
  required to melt ice, 1,783.
  saturated steam, total, 1,797.
  sensible, des., ills., 1,793.
  specific, 1,776.
    apparatus, Tyndall's, ills., 1,776.
    example, 1,777.
    gases, table, 1,778.
    liquids and solids, table, 1,777.
    standard, 1,776.
    superheated steam, 1,810.
  transfer, def., 1,757.
    method, 1,774–1,973.
    rate of, 1,758.
  transmission, 1,976.
  unit(s), 1,756.
    in internal latent heat, 1,795.
    in sensible heat, 1,793.
    old def., 1,756.
  zero, absolute, diag., 1,765.
Heaters, feed water, 2,256.
Heating boiler, see Boiler(s), *heating*.
Heating surface, measurement, 1,975.
  classification, steam boiler, 1,955.
  essential qualities, 1,973.
  extensiveness, 1,974.
  form, 1,974.
  material, nature, 1,973.
Heating surface, steam heating boilers, inadequate,
    ills., 2,128, 2,130.
  tubular, characteristics, diag., 1,964.
  water tube boiler classification, 2,058.
Heating value, bagasse, 1,837.
  coal, fuel analysis, calc., 1,911.
    tar, 1,838.
  dry fuel, formula, 1,864.
  fuel, available, 1,865.
    determining, ultimate analysis, method, 1,863.
    high, 1,869.
    natural gas, 1,843.
  of acetylene, 1,852.
  of benzole, 1,852.
  of coal, 1,828.
    different, causes, 1,823.
  of coke, 1,833.
  of ethylene, 1,852.
  of gaseous fuels, 1,869.
  of marsh gas, 1,852.
  of methane, 1,852.
  olefiant gas, 1,852.
  of straw, 1,836.
  of tan bark, 1,836.
  of wood and coal, comparative, 1,835.
  oil tar, 1,839.
  petroleum, 1,840.
  sawdust, 1,837.
  ultimate analysis, 1,904.
Heine superheater, ills., 2,260, 2,261.
Hempel pipette, flue gas analysis, ills., 1,933.
High, heating value of fuels, 1,869.
  pressure, Scotch boiler, modern, ills., 2,050.
  temperature, colors, 1,770.
Hoar frost line, 1,780.
Hollow stay, boiler construction, ills., 2,205.
Homogeneity, ills., 2,200, des., 2,021.
Homogeneous, def., 1,996.
Horizontal, fire tube boiler vertically set, 2,101.
  return fire tube boiler, triplex, ills., 2,101.
    des., 2,027.
    evolution, ills., 2,026.
    ills., 2,032.
  steam heating boiler, assembling, ills., 2,142–2,143.
    Capitol, ills., 2,139.
    ills., 2,129.
    circulation, Ideal, ills., 2,147.
  water tube boiler, non-sectional, Casey-Hedges, ills., 2,078.
    non-sectional, Keeler, ills., 2,078.
Horse power of, locomotive boilers, 2,113.
  marine boilers, 2,113.
Hot short, def., 1,996.
Hydro-carbon(s) acetylene, heating value 1,852.
  benzole, heating value, 1,852.
  ethylene, heating value, 1,852.
  gases, complete combustion, how obtained, 1,878.
  marsh gas, heating value, 1,852.
  methane, heating value, 1,852.
  olefiant gas, heating value, 1,852.
Hydrogen, des., 1,848.

I

Ice, fusion of, changes, necessary, 1,781.
  heat required to melt, 1,783.
  melting, effects of pressure on, ills., 1,783.
    point, 1,784.
    volumetric change, 1,785.
  regelation, effects of, ills., 1,783, 1,784.
  specific gravity of, 1,788.
Ideal horizontal steam heating boiler, circulation, ills., 2,147.
  gas flow, Ideal, ills., 2,147.
Ideal syphon steam regulator, steam heating boiler, ills., 2,152.
Ignition, point, combustion, 1,849.
  wiring, Emerson calorimeter, methods, ills., 1,908.
Inclined tube, method of circulating water in boiler, ills., 1,803.
Incombustible matter in fuels, 1,885.
Influence of cold on molecular vibration, 1,755.
Insulation, steam boiler, 2,006.
Intensity, smoke, 1,880.
Internal, external furnaces, steam boiler, comparison, 1,984.
  fire box, fire tube boilers, vertical, 2,102.
  latent heat, 1,794, 1,795.
  work of fusion, 1,786.
Internally fired boiler, 1,971, 1,984, 2,033.

International, *base*, steam heating boiler, ills., 2,145.
steam heating boiler, ills., 2,144.
steam heating boiler, parts, ills., 2,131.
steam dome, steam heating boiler, ills., 2,151.
Iron, cast, see Cast iron.

J

James' water tube boiler, ills., 2,061.
Jaw stay, steam boiler construction, des., ills., 2,213.
Jet pump, flue gas analysis, Richards, ills., 1,927.
Joint(s), boiler construction, butt, straps, equal, ills., 2,186.
objection, 2,168.
butt, 2,179, 2,181, 2,182, 2,184.
efficiency, diag., 2,160.
ills., 2,169.
circumferential, ills., 2,191.
lap, butt, diff., 2,167, ills., 2,168.
ills., 2,177, 2,178.
single, 2,173.
pull, effect, diag., 2,170.
riveted A.S.M.E, Boiler Code, 2,176–2,188, 2,191.
calculation, 2,172.
classes, 2,167.
efficiency, 2,171.
strength, 2,160.
U. S. Marine rules, 2,189–2,
Wicks, table, 2,188.
Jones coal samples, fuel analysis, ills., 1,905.

K

Keeler non-sectional horizontal water tube boiler, ills., 2,078.
Kindling, point, combustion, 1,849.
temperatures fuels, 1,850.
Kingsford special boiler, ills., 2,113.

L

Ladd steam drum, steam boiler construction, ills., 2,245.
Lamp, *Davy's*, experiment with, ills., 1,849.
ills., 1,847.
principles, ills., 1,848.
Lancashire boiler, *breeches flued*, des., 2,037, 2,038.
without breeches, ills., 2,036.
Lap and butt joints, steam boiler construction, 2,167, ills., 2,168.
Lap joint, steam boiler construction, ills. 2,169.
ills., 2,177, 2,178.
objections, 2,168.
single, 2,173.
Latent heat, des., ills., 1,794, 1,796.
of fusion, 1,781, 1,783.
of vaporization, def., 1,791.
Leslie's, cube, ills., 1,773.
experiment of freezing water, as it boils, diag., 1,782.
Leg marine boiler, ills., 2,054.
Liberating surface, insufficient, results, diag., des., 1,979.
Ligament, efficiency, diag., 2,196.
Lignite, coal, des., 1,827.
combustion, air required for, 1,861.
youngest coal, 1,824.
Linear expansion, coefficient, def., 1,772.
Liquid, and gas fuels, comparison, 1,843.
def., 1,780.
expansion, 1,788.
Liquid fuel, 1,839–1,842.
advantages, 1,839.
analysis, 1,917.
sulphur test, 1,918.
ultimate, 1,917.
crude oil, composition, 1,839.
gas fuel, comparison, 1,843.
oil, ***U. S. Navy*** report, 1,841.
petroleum, heating value, 1,840.
kinds, 1,839.
Liquid(s), least density, point, 1,788.
maximum density, 1,788.
volumetric changes, 1,788.
molecular movements, 1,756.
specific heat, table, 1,777.
Load, effects on water tube boilers, 2,057.
test, steam boiler material, 2,007.
Locomotive boiler(s), 2,045.
classification, 1,963.
horse power, 2,113.
differences, 2,046.
semi-portable, ills., 2,046.
wagon top, com., 2,046.
Locomotive type marine boiler, Rees, ills., 2,055.
Long pass, short pass, steam heating boiler, characteristic, ills., 2,136.
Longitudinal, drum, elementary non-sectional water tube boiler, ills., 2,066.
header drum, ills., 2,246.
Luken diagonal stay, ills., 2,210.
Lyons combined boilers, adv., 2,120.

M

Magee steam heating boiler, parts, ills., 2,138.
Mahler calorimeter, parts, ills., 1,906.
Malleable, castings, 1,994.
iron, production, methods, 1,988.

Malleable, iron,—*Continued*
steam boiler construction, 2.000.
pig iron steam boiler, materials. 1.994.
Malysheff method determining elastic limits, diag., 2,002.
Manhole, see Boiler(s) construction, *manhole.*
Manifold, steam boiler construction, 2,251.
Manning, boiler, ills., 1,958.
special boiler, des., 2,104.
Marine boiler(s), Clyde & Scotch, difference, 2,054.
des., ills., 2,047.
Graham, dry pipe for vertical boiler of steamer *Stornoway II*, ills., 2,044.
horse power, 2,113.
leg, ills., 2,054.
over discharge, Mosher, ills., 2,249.
triple tube, Mosher, ills., 2,087.
position of, 1,984.
plate requirements, 2,156.
under discharge, Yarrow, ills., 2,249.
vertical, through tube, ills., 2,048.
Marine Iron Works, Clyde boiler, ills., 2,052.
special marine shell boiler, ills., 2,053.
submerged tube shell boiler, ills., 2,049.
Marine, *shell boiler*, locomotive type, ills., 2,055.
Marine Iron Works, ills., 2,053.
steam boiler classification, 1,963.
transverse drum, boiler construction, Babcock & Wilcox, ills., 2,246.
Marsh gas, heating value, 1,852.
Matter, gas, molecular, moverts, 1,756.
liquid, molecular movements, 1,756.
solid, molecular movement, 1,756.
three states of, 1,755, 1,756.
volatile, des., 1,823.
Maximum, *density*, 1,788.
liquid, 1,788.
volumetric changes, 1,788.
pitch, screwed staybolts, 2,219.
Maxwell's definition of a solid, 1,779.
Mechanical equivalent of heat, 1,770.
ills., 1,771.
Melting, *ice*, heat required 1,783.
volumetric change, 1,785.
point, of bricks, 2,006.
ice, 1,784.
of solids, def., 1,996.
Mercury, *thermometers*, advantages of using, 1,759.
cons., ills., 1,758.
well, temporary thermometer connection, Tagliabue, ills., 1,761.
Metallic, *pyrometer*, calibrating, 1,769.
handling, precautions, 1,769.
Metals, heat, conductivity, ills., 1,775.
Methane, heating value, 1,852.
Micrometer, 2,002–2,005.
Modified Clyde type, special boiler, 2,109.
Modulus of, elasticity, testing 2,009.
rupture, 2,009.
Molecule, def., 1,755.
Molecular, *movements*, gases, 1,756.
temperature on, 1,757.

Molecular,—*Continued*
vibration, cold, influence on, 1,755.
Monitor coil boiler, ills., 2,144.
Mortar, fuel analysis, bell, ills., 1,904.
Mosher, over discharge marine boiler, ills., 2,249.
triple tube over discharge marine boiler, ills., 2,087.

N

National steam heating boiler, fire pot, ills., 2,154.
parts, ills., 2,132.
section, ills., 2,153.
Natural gas, heating value, 1,843.
Nickel, steel, use, 2,004.
Niclausse porcupine boiler, ills., 2,092.
Nipple, push, steam heating boiler, ills., 2,139.
Nitrogen, air, effects, 1,856.
Non-sectional boiler, 1,967.
horizontal water tube boiler, Casey-Hedges, ills., 2,078.
Keeler, ills., 2,078.
Wicks, ills., 2,081.
water tube boiler, des., 2,064.
elementary, longitudinal drum, ills., 2,066.
transverse drum, ills., 2,067.
Nozzle, calorimeter, sampling, Stott & Pigott, ills., 1,818.
sampling, calorimeter, 1,820.

O

Ofeldt automobile boiler, ills, 2,088.
Oil, *coal*, evaporation, comparative, 1,841.
fuel value, relative, 1,840.
combustion, air required for, 1,861.
crude, composition, 1,839.
fuel, 1,839–1,842.
advantages, 1,839.
U. S. Navy report, 1,841.
tar, 1,839.
composition, chemical, 1,839.
Olefiant gas, heating value, 1,852.
Olefin, des., 1,839.
Olsen, automatic testing machine, ills., 2,010.
deflection instrument, ills., 2,007.
extension and compression micrometer, ills., 2,005.
four screw testing machine, ills., 1,999.
micrometer extensometer, ills., 2,002–2,004.
securing test tool, ills., 2,000.
tortion attachment, universal testing machine, ills., 2,001.
Open hearth, process, cast iron, ills., 1,992.
steel, def., 1,994.
Orifice plate, throttling calorimeter, 1,820.

Orsat apparatus, care of, 1,929.
  chemical reagents used, 1,931.
  four pipette, ills., 1,932.
  precision 100 cc. standard, ills., 1,936.
  three pipette connection, ills., 1,930.
Over discharge, *marine boiler*, Mosher, ills., 2,249.
    triple tube, Mosher, ills., 2,087.
  water tube boiler, ills., 2,065.
Oven, double wall, fuel analysis, Eimer & Amend, ills., 1,895.
  drying, Gaertner, ills., 1,896.
Oxide, iron, effects of, in ashes, 1,886.
Oxygen, determination of, 1,904.
  necessary for complete combustion, amount, 1,854.
  required for combustion, table, 1,865.
  supporter of combustion, 1,845.
  volume, finding corresponding volume air, 1,936.
  where obtained, 1,845.

P

Palm stay, des., 2,212, ills., 2,213.
Paraffin, des., 1,839.
Parallel, arrangement, water tube boiler, accessibility, 2,067, ills., 2,068.
  connection, elementary steam boiler, ills., 1,804.
    water tube boiler, ills., 2,059.
      elementary, ills., 2,068.
Parker, water tube boiler, 2,096, 2,097.
Parr calorimeter, apparatus for use with, ills., 1,913.
  cartridge details, ills., 1,910.
Passage(s), *gas*, stem boiler, 1,977.
Peet, 1,833, 1,834.
  machine, des., 1,834.
Pellet press, fuel analysis, ills., 1,904.
Petrie's water pockets, ills., 2,039.
Petroleum, advantages, 1,839.
  heating value, 1,840.
Pfaundler's method for radiation correction, calorimeter, 1,912.
Phoenix-Manning vertical boiler, ills., 2,103.
Phosphorous steel, boiler materials, use, 2,003.
Photometer, sulphur, fuel analysis, Eimer & Amend, ills., 1,914.
Pig iron, 1,993, 1,994.
Pipe, blow, combustion, ills., 1,860.
Pipe boiler(s), 2,117.
  des., 2,070.
  features, 2,073.
  Taylor, ills., 2,116.
  use, 2,074.
Pipe, difference between tube and, 1,972.
  threads, number, minimum, 2,235.
  water tube boiler, ills., 2,095.
Pitch, of stay, tube, 2,211.
  rivets, 2,170, ills., 2,171.
    diagonal, 2,170, ills., 2,171.
Pitch, *rivets*,—*Continued*
    maximum, 2,219.
Plain cylinder, shell boiler, ills., 2,027.
Plate(s) *boiler*, marine requirements, 2,156.
    silicon, effect, 2,005.
  crusher, fuel analysis, ills., 1,902.
  orifice, throttling calorimeter, ills., 1,820.
  steam boiler construction, 2,156.
  side, boiler construction, ills., 2,216.
Platinum-rhodium thermo-couple, Brown, ills., 1,768.
Pocket CO_2 recorder, *Bacharach*, ills., 1,937.
    manipulation, diag., 1,938.
Pockets, water, shell boiler, Petrie, ills., 2,039.
Point, boiling, thermometer, method of determining, ills., 1,762.
  fixed, thermometer scale, 1,760.
  kindling, combustion, 1,849.
  melting, ice, 1,784.
Porcupine, boiler, 2,089.
  classification, 2,090.
  Niclausse, ills., 2,092.
  Racine, ills., 2,091.
  Shipman, ills., 2,090.
  tubes in, 1,972.
  Ward, Field or double drop tube 2,072.
Pratt & Whitney stay bolt taps, ills., 2,204, 2,207.
Precision, *Boiler tester*, flue gas analysis, ills., 1,935.
  flue gas collector, ills., 1,923.
Preheating air supply, combustion, effects, 1,883.
Pressure, *atmospheric*, sea level, 1,790.
    variations, 1,790.
  melting ice by, 1,785.
  on boiling point, effect, 1,790.
  on melting ice, effects of, ills., 1,783.
  on melting point, effect, 1,784.
  steam boiler, bursting, diag., 2,162.
    working, des., 2,163, 2,164.
Priming, steam boiler, 1,980.
Prosser segment tube expander, ills., 2,240.
Proximate analysis, coal, 1,889.
  combustion, 1,873.
Puddled, iron, def., 1,994.
  steel, steam boiler, materials, def., 1,994.
Puddling, furnaces, ills., 1,989.
  process, wrought iron, 1,988.
Pull, joints, effect, diag., 2,170.
Push nipple, steam heating boiler, ills.. 2,139.
Pyrometer(s), *metallic*, calibrating, 1,769.
    precaution necessary, 1,769.
    principles, 1,766.
    simple, working, 1,768.
  types, 1,766.

R

Racine porcupine water tube boiler, ills., 2,091.
Radial, fire tube boiler, vertical, 2,105.
  stay, des., ills., 2.217.

Radial,—*Continued*
- T Bars, ills., 2,221.

Radiation, calorimeter, heat, correction, 1,912.

Radiometer, ills., 1,773.

Rapid circulation, steam boiler, desirability, des., diag., 1,978.
- *evaporation*, steam boiler, 1,977.

Reaumur thermometer scale, 1,764.

Recorder CO_2, see CO_2 recorder.

Rees, locomotive type marine boiler, ills., 2,055.
- Western river type flue boiler, ills., 2,056.

Refined cast iron, def., 1,994.

Regelation, effects of, ills., 1,783, 1,784.

Regulator steam heating boiler, syphon steam, Ideal, ills., 2,152.

Relative, conductivity of heat, table, 1,775.
- fuel value of coal and oil, 1,840.

Report, of *U. S. Navy* on oil fuel, 1,841.

Resilience, steam boiler materials, def., 1,996.
- test, steam boiler materials, 2,011.

Return, *fire tube boilers*, horizontal, duplex, ills., 2,100.
  - horizontal, triplex, ills., 2,101.
  - object, 2,106.
  - vertical, Webber, ills., 2,107.
- flue boiler, single, ills., 2,028.
- tube boiler, features, 2,056.
- *tubular boiler*, 1,970.
  - des., 2,027.
  - evolution, ills., 2,026. ills., 2,032.

Reynolds, boiler, crown sheet, ills., 2,106.
- vertical fire tube boiler, ills., 2,105.

Richards jet pump, ills., 1,927.
- flue gas analysis, operation, 1,927.

Riehle, specimen holders, diag., 2,011.
- testing machine, ills., 2,015.
- weighing beam, ills., 2,009.

Ringlemann's, readings, plotting, diag., 1,802
- scale for grading smoke density, ills., 1,881.
- smoke chart, diag., 1,880.

Rivet, steam boiler construction, 2,170,
  - diagonal, 2,170, ills., 2,171.
  - *pitch*, ills., 2,171.

Riveted joint(s), *A.S.M.E. Boiler Code*, 2,176–2,188, 2,191.
- calculation., 2,172.
- classes, 2,167.
- efficiency, 2,171.
- straight, 2,160.
- strength, 2,172.
- *U. S. Marine Rules*, 2,189–2,190.
- Wicks, table, 2,188.

Rivet pitch, 2,170, ills., 2,171.

Riveted stay, des., ills., 2,209.

Riveting man hole frames, ills., 2,231

Rivets, fracture between, ills., 2,175. 5.
- split and double shear, ills., 2,175.

Roberts water tube boiler construction, ills., 2,071–2,076.

Roller tube expander, ills., 2,240.

Round vertical steam heating boiler, ills., 2,128.

Rules, construction, steam boiler, 2,155.

Rupture, modulus, 2,009.

Rust, effect on steel, 1,990.

S

Safety, factor of, 2,007.
- *lamp*, *Davy's* cons., 1,847.
  - principle, ill., 1,848.
- steam boiler comstruction, factor, 2,163.

Sample(s), *coal*, preparing, ills., 1,890–91.
  - Jones, ills., 1,905.
- flue gases, 1,923.
- Hays, automatic flue gas collector, collecting, 1,924.

Sampling, *nozzle*, *calorimeter*, 1,820.
  - Stott & Pigott, ills., 1,818.
- tube, flue gas analysis, location, 1,925.

Sarco, calorimeter, fuel analysis, ills., 1,907.
- CO_2 recorder, 1,940, 1,941, 1,943, 1,948.

Saturated steam, def., 1,789.
- total heat, 1,797.

Sawdust, fuel, condition, necessary, 1,837.

Scale(s), for grading smoke density, Ringelmann, ills., 1,831.
- scleroscope, 1,997.
- *thermometer*, centigrade, 1,760, 1,763.
  - comparison, 1,763, 1,764.
  - des., 1,762.
  - Fahrenheit, 1,760. 1,763.
  - Reaumur, 1,764.
  - subdivision, 1,762.
  - types, 1,763.
  - use, 1,759.

Scleroscope, ills., 1,997, 1,998.

Scheibler, dessicator, ills., 1,899.

Scientia calorimeter, ills., 1,915.

Scotch boiler, features, 2,048.
- Clyde, diff., 1,970.
- form, 2,054.
- modern, high pressure, ills., 2,050.
- *shell boiler*, parts, 2,049.
  - single furnace, ills., 2,051.

Screwed stays, 2,205, 2,206, 2,217.

Sea level, atmospheric pressure, 1,790.

Seabury bent water tube boiler, ills., 1,960.

Seam, steam boiler construction, element, ills., 2,173.

Sectional, boiler, Graham, ills., 2,077.
- down flow water tube boiler, Parker, diag., 2,096.
- headers, ills., 2,254.
- horizontal water tube boiler, Babcock & Wilcox, ills., 2,080.
- *steam*, boiler, 1,967.
  - heating boilers, Gurney, ills., 2,149, 2,150.
- view, National steam heating boiler, ills., 2,153.
- *water tube boilers*, adv., 2,069.
  - parallel, elementary, ills., 2,068.
  - parts, 2,066.
  - series, elementary, ills., 2,068.

Segment tube expander, steam boiler construction, Prosser, ills., 2,240.

Semi-anthracite coal, des., 1,825.
Semi-bituminous coal, des., 1,826.
Semi-portable locomotive shell boiler, ills., 2,046.
Sensible heat, des., ills., 1,793.
Separating calorimeter, des., 1,815.
  error, percentage, 1,811.
  operation, 1,816.
Series, *connectors*, elementary steam boiler, ills., 1,804.
    water tube boiler, ills., 2,058.
  parallel, pipe boiler, Almy, ills., 2,095.
    water tube boiler, 2,091.
  sectional water tube boiler, elementary, ills., 2,068.
Setting, steam boiler, materials used in, 1,985.
Shear, single, double, diff., 2,170.
  testing, single and double, ills., 2,016.
  test, steam boiler materials, 2,011.
Shearing, ills., 2,172.
  test, steam boiler materials, kinds, 2,017.
    tool, Olsen, ills., 2,000.
Sheet, crown, Reynolds, boiler, ills., 2,106.
  des., 2,025.
Shell and water tube boiler, sensitiveness, diag., 1,982.
Shell boiler, see Boiler(s), *shell*.
Shipman porcupine boiler, ills., 2,090.
Shore sceleroscope outfit, ills., 1,998.
Short, cold, def., 1,995.
  hot, 1,996.
Silicon in boiler plate, effect, 2,005.
Silsby fire tube water tube fire engine boiler, ills., 2,125.
Simmance-Abady CO_2 recorder, working parts, ills., 1,946.
Single, and double shear test, ills., 2,016.
  double shear, 2,170.
  flue Clyde type boilers, ills., 2,109.
  furnace Scotch shell boiler, ills., 2,051.
  lap joint, 2,173.
  return flue boiler, ills., 2,028.
  tube boiler, 1,967.
Sling straps, boiler construction, ills., 2,216.
Smelting copper, methods, 1,985.
Smith-Manning special boiler, ills., 2,104.
Smoke, *black*, indication, 1,877.
    particles, 1,875.
  cause of, 1,876, 1,877.
  chart, Ringelmann, diag., 1,880.
  colored, indication, 1,876.
  combustion, classification, 1,880.
  def., 1,875.
  density, determining, electrical method, 1,882.
    grading, 1,881.
      Ringelmann scale, ills., 1,881.
Socket stays, des., ills., 2,207.
Soft steel, carbon percentage, 1,990.
Solid(s), des., 1,779.
  Maxwell's, def., 1,779.
  molecular movement, melting point def. 1,756, 1,996.
  specific heat, table, 1,777.
Soot, cause of, ills., 1,876.
Spade peet, des., 1,834.
Special boiler(s), see Boilers *special*.
Specific gravity, of ice, 1,785.
  def., 1,996.
Specific heat, 1,776, 1,777.
  apparatus, Tyndall's, ills., 1,776.
  def., 1,776.
  gas variations, 1,778.
  liquids, table, 1,777.
  of gases, table, 1,778.
  of solids, table, 1,777.
  of super-heated steam, 1,810.
  standard, 1,776.
Stanley automobile boiler, ills., 1,965.
States of matter, 1,755.
Stay, boiler construction, hollow, ills., 2,205.
  screwed, drilled holes, object, 2,206.
    flaws, des., ills., 2,206.
Stay bolts, screwed, pitch, maximum, 2,219.
  des., ills., 2,202.
  breaking, 2,207.
  top, ills., 2,203.
    thread, 2,205.
    ills., 2,204.
Stay, gusset, stress, 2,212.
  jaw, ills., 2,213.
  palm, ills., 2,212, 2,213.
  riveted, boiler des., ills., 2,205.
  rods, steam boiler, des., ills., 2,208.
  screwed, diameter, 2,205.
  crow foot, des., 2,213, ills., 2,212.
  diagonal, Luken, ills., 2,210.
    types, ills., 2,210.
  fastening, methods, ills., 2,218.
  gusset, des., ills., 2,211.
  jaw, des., ills., 2,213.
  palm, des., 2,212, ills., 2,213.
  radial, des., ills., 2,217.
  socket, des., ills., 2,207.
  stress, minimum, 2,221.
  tube, ends, ills., 2,209.
    pitch, 2,211.
Staying boiler head, ills., 2,215.
Steam, boilers, see Boilers.
  calorimeter, see Calorimeter.
  circulation of water in boilers, ills., 1,803.
  condensation, causes, 1,799.
  definition, 1,789.
  dome, steam heating boiler, 2,152.
    International, ills., 2,151.
  drum, Vogt, ills., 2,251.
    class., 2,244.
    Ladd, ills., 2,245.
  dry, 1,789.
  engine, *fire*, boiler, fire tube, water tube, Silsby, ills., 2,125.
    shell water tube, Fox, ills., 2,122.
  evaporation factor, see Evaporation factor.
  formation, 1,790, 1,800.
  gas, 1,790.
  gaseous, 1,790.
  generator(s), boiler, diff., 1,972.
    types, 1,972.
  heating boiler, see Boiler, heating
  ice to, 1,779–1,820.

- **Steam,**—*Continued*
  - *latent heat,* des., ills., 1,794.
    - external, 1,795.
  - parallel connection, elementary boiler, ills., 1,804.
  - pressure, classification steam boilers, 1,959.
  - *pump,* flue gas, analysis, des., 1,928.
    - operation, 1,928.
  - quality, 1,811.
  - regulator, steam heating boiler, syphon, 2,152.
  - space, steam boiler, 1,978.
  - *superheated,* 1,790.
    - ice to steam, 1,810.
    - specific heat, 1,810.
  - wet, des., 1,789.
- Steamer, ***Norwood,*** boiler, ills., 2,087.
- Steel, angle stays, 2,214.
  - aluminum, use, 2,004.
  - application to boiler construction, 1,990.
  - *Bessemer,* qualities, 1,992.
    - def., 1,993.
    - process, 1,992.
  - *carbon,* percentage, 2,002.
    - carbon, uses, 2,002.
  - *cast,* carbon, percentage, 1,990.
    - def., 1,993.
  - castings, def., 1,994.
  - converted, def., 1,993.
  - crucible, def., 1,993.
  - def., 1,994.
  - manganese, use, 2,004.
  - nickel, use, 2,004.
  - open hearth, def., 1,994.
  - phosphorus, use, 2,003.
  - physical properties, 2,001.
  - puddled, def., 1,994.
  - rust; effects, 1,990.
  - sheer, def., 1,994.
  - soft, carbon, percentage, 1,990.
  - steam boiler materials, 1,993.
  - sulphur, use, 2,004.
- Stirling bent water tube boiler, ills., 2,084.
- Stott & Pigott sampling nozzle, calorimeter, ills., 1,818.
- Straps, sling, ills., 2,216.
- Straw, composition, 1,836.
  - heating value, 1,836.
- Strength (of) riveted joint, 2,160, 2,172.
  - *steam boiler,* shell, calculating, 2,159.
    - materials, def., 1,996.
- Stress, bending, def., 2,006.
  - gusset stay, 2,212.
  - test, 2,011.
- Submerged tubes, shell boiler, 2,043.
  - shell boiler, Marine Iron Works, ills., 2,049.
  - vertical boiler, ills., 2,042.
- Sulphur, combustion, des., 1,849.
  - correction, calorimeter, 1,914.
  - fuel analysis, determining, 1,903.
  - photometer, fuel analysis, Eimer & Amend, ills., 1,914.
  - steel, steam boiler material, use, 2,004.
  - testing for, 1,899.
- **Sulphur,**—*Continued*
  - test liquid fuel analysis, 1,918.
  - testing, Eschkas method, 1,900.
- Superheated steam, 1,790.
  - specific heat, 1,810.
- Superheaters, boiler construction, 2,256.
  - elements, Foster, ills., 2,259.
  - flooding, object, 2,259.
  - Foster, ills., 2,257, 2,258.
  - Heine, ills., 2,260, 2,261.
  - location, 2,258.
- Surface(s), flat, reinforcement, 2,201.
  - grate, boiler, 2,113.
  - *heating,* measurement, 1,975.
    - form, 1,974.
    - tubular, characteristic, diag., 1,964.
  - *steam heating boiler,* efficiency, diag., 2,135.
    - extensiveness, 1,974.
    - inadequate, effect, ills., 2,130.
  - *liberating,* 1,978.
    - insufficient, results, diag., des., 1,979.
- Surfusion, 1,785.
  - unstable condition, 1,785.
  - temperature change, 1,785.
- Syphon steam regulator, steam heating boiler, Ideal, ills., 2,152.

T

- Table (of), comparison of gas and coal, 1,843.
  - air required for combustion at 1,865. 1,861.
  - CO_2 and excess air, 1,953.
  - factors of evaporation, 1,807, 1,808.
  - heat of combustion, fuel analysis, 1,912.
  - relative conductivity of heat, 1,775.
  - riveted joints, Wicks Boiler Co., 2,188.
  - *specific heat,* of gases, 1,778.
    - of liquids, 1,777.
    - of solids, 1,777.
  - water evaporation, fuels, 1,844.
- Tagliabue, mercury well, 1,761.
  - thermometer, ills., 1,759, 1,760.
- Tailor pipe boiler, ills., 2,116.
- Talbot boiler, water tube, ills., 2,077, 2,111.
- Tan bark, composition, 1,836.
  - fuel, wet, proper use, 1,836.
  - heat value, 1,836.
  - use of, 1,836.
- Tap(s), *stay bolt,* ills., 2,203.
  - ills., 2,204.
    - thread, 2,205.
- Tar, *coal,* composition, chemical, 1,838.
    - heating value, 1,838.
  - *oil,* 1,839.
    - composition, chemical, 1,839.
    - heating value, 1,839.
- Temperature, 1,757–1,770.
  - *absolute,* 1,764.
    - value, 1,766.
    - zero, ills., 1,765.
  - change in surfusion, 1,785.

- **Temperature,**—*Continued*
  - critical, diag., 1,781.
  - during change of state, 1,782.
  - *furnace,* combustion, calculating, 1,881.
    - increasing, 1,883.
  - high, colors of, 1,770.
  - lowering, closed vessel, effects, 1,799.
  - measurement, 1,757.
  - molecular movement, influence on, 1,757.
  - of one degree, rise, def., 1,763.
- Tensile, strength, 2,013.
  - *test,* boiler materials, ills., 2,012, 2,015.
    - ills., 2,012.
- Tension test, 2,014, 2,013,
- Tenacity, steam boiler materials, def., 1,996.
- Test, calorimeter, des., 1,909.
  - cold bending, des., 2,020.
  - hardness, 2,020.
  - homogeneity, ills., 2,020, des., 2,021.
  - sulphur, liquid fuel analysis, 1,918.
  - tensile, ills., 2,012, 2,015.
- Testing, fuel, see Fuel analysis
  - *machine,* automatic, Olsen, ills., 2,010.
    - Olsen four screw, ills., 1,999
    - Universal tortion attachment, Olsen, ills., 2,001
  - steam boiler materials, see Boiler materials, *testing.*
- Thermal unit, British, definition, 1,756.
- Thermo-couple, Foxboro, ills., 1,769.
  - platinum-rhodium, Brown, ills., 1,768.
- Thermometer(s), boiling point, method of determining, ills., 1,762.
  - connections, Tagliabue, permanent, ills., 1,760.
  - freezing point, ills., 1,761.
  - *mercury,* advantages of using, 1,759.
    - cons, ills., 1,758.
    - use of, 1,758.
  - ordinary, contraction, 1,759.
  - principles, basic, 1,758.
  - scale, see Scale,
  - Tagliabue, ills., 1,759, 1,761.
  - temporary connection, mercury well, use of, 1,757.
- Thompson calorimeter, fuel analysis, 1,918.
- Thread(s), pipe, steam boiler construction, number, minimum, 2,235.
  - stay bolt tap, boiler construction, 2,205.
  - stripping, steam boiler construction, prevention, 2,204.
- Three pass tubular shell boiler, adv., 2,031.
- Three pipette Orsat apparatus, ills., 1,930.
  - states of matter, ills., 1755, 1,756.
- Throttling calorimeter, compact, 1,814, ills., 1,819.
  - *Ellison,* construction, 1,813.
    - operation, 1,813.
  - error, percentage, 1,811.
  - ice to steam, orifice, plate, ills., 1,820.
- Through tube, 1,967.
  - vertical marine boiler, ills., 2,048.
- Tools *taps, stay bolt,* thread, 2,205.
    - ills., 2,203.
    - Pratt & Whitney, ills., 2,204, 2,207.
- Torch, blast, laboratory, Clayton & Lambert, ills., 1,900.
- Tortion attachment, Olsen, ills., 2,001
- Tortional test, testing, des., ills., 2,017.
- Towering temperature enclosed vessel, 1,799.
- Transfer of heat, def., 1,757.
  - methods, 1,774. 1,973.
  - rate of, 1,758.
- Transmission of heat, 1,976.
- Transverse drum, elementary non-sectional water tube boiler, ills., 2,067.
  - test, ills., 2,014, des., 2,016.
- Travel, gas, steam heating boiler, diag., 2,134.
- Trevithick shell boiler, 2,033, 2,034.
  - ills, 2,034.
- Tri-pass fire tube boiler, extended shell, object, 2,110.
- Triple, point, ice to steam, diag., 1,780.
  - tube over discharge marine boiler, Mosher, ills., 2,087.
- Triplex horizontal return fire tube boiler, ills., 2,101.
- Tube(s), arrangements, steam boiler, various, ills., 1,966.
  - difference between pipe and, 1,972.
  - double, 1,967.
  - ends, stay, ills., 2,209.
  - *expander,* Roller, ills., 2,240.
    - segment, Prosser, ills., 2,240.
  - *Field,* 1,967.
  - fire and water, diff., 2,023.
  - *flue,* difference, 2,025.
    - steam boilers, diff., des., ills., 1,963.
  - Galloway, 1,970.
  - *grouping, steam boiler,* 1,957.
    - water tube boiler, 2,058.
  - parallel and series, 2,067.
  - pipe, steam boiler, diff., 1,972.
  - *position,* water tube boiler, 2,059.
    - steam boiler classification, 1,957.
  - sampling, location, 1,925.
  - spacing, des., ills., 2,193–2,198.
  - *stay,* 2,209.
    - pitch, 2,211.
  - steam, fastening, 2,241.
  - single, 1,967.
  - submerged, shell boiler, 2,043.
  - U, boiling water, circulating in, 1,801.
    - various, ills., 1,960, 1,962.
    - water, Graham boiler, ills., 2,144.
  - water tube boilers, bent, various, 2,082.
- Tubular, boiler, horizontal returns, 2,027.
  - heating surface, characteristic, 1,964.
  - *shell boiler,* horizontal return, ills., 2,032.
    - three pass, adv., 2,031.
- Turnbuckle, ills., 2,209.
- Two pass fire tube boiler, Casey-Hedges, ills., 2,110.
- Tyndall's specific heat apparatus, ills., 1,776.
  - auxiliary boiler room CO_2 recorder, ills., 1,754.
    - Vehling *CO_2 recorder,* charts, diag., 1,952, 1,950.

U

- Ultimate analysis, coal, 1,889, 1,900.
  - *combustion*, 1,858.
    - calculation from, 1,863.
  - heating value, 1,903, 1,904.
- Ultimate, liquid fuel analysis, 1,917.
  - strength, 2,013.
- Under discharge, marine boiler, Yarrow, ills., 2,249.
  - water tube boiler, ills., 2,065.
- Underfeed steam heating boiler, Williamson, ills., 2,137.
- Union Iron Works, drum end, steam boiler construction, ills., 2,247.
  - hand hole plate parts, ills., 2,256.
- Unit(s), British thermal, def., 1,756.
  - *heat*, internal latent heat, 1,795.
    - old def., 1,756.
    - sensible heat, 1,793.
- Universal testing machine, Olsen, ills., 2,001.
- Up flow, circulation, water tube boiler, ills., 2,063.
  - down flow water tube boilers, 2,093.
- Upright boiler, Bigelow, ills., 2,041.
  - des., 2,039.
  - dry pipe, Graham, ills., 2,044.
  - evolution, diag., 2,040.
  - types, 2,041, des., 2,041.
  - water level, proper, 2,044.
- *U. S. Navy* report on oil fuel, 1,841.
- U tube, boiling water circulating in, 1,801.

V

- Vacuum, calorimeter, Emerson, ills., 1,909.
- Vapor formation, 1,791.
- Vaporization, des., 1,791.
  - external work, 1,795.
  - in a closed vessel, effects, 1,799.
  - latent heat, def., 1,791.
  - phenomena, ills., 1,792.
  - work of, stages, 1,793.
- Vegetable origin of coal, evidence, 1,824.
- Vertical boiler(s), des., 2,039.
  - Berry, ills., 2,108.
  - defects, 2,042.
  - Reynolds, ills., 2,105.
  - submerged tube, ills., 2,042.
  - various, ills., 1,958.
- Vertical, internal fire box, fire tube boilers, 2,102.
  - marine boiler, through tube, ills., 2,048.
  - radial fire tube boiler, 2,105.
  - return fire tube boiler, Webber, 2,107.
  - setting, fire tube boiler, ills., 2,102.
  - steam heating boiler, round, ills., 2,128.
  - tubular steam heating boiler, Andrews, ills., 2,136.
- Vessel, closed, vaporization, effects, 1,799.
- Visible flame, 1,875.
- Volatile matter, 1,889, 1,895
  - des., 1,823.
  - coals, percentage curves, 1,872.
- Volumetric, analysis of air, 1,845.
  - change(s), of freezing water, 1,785.
    - with maximum density, 1,788.
- Vogt, steam drum, ills., 2,251.
  - *water*, drum ills., 2,251.
    - tube boiler, ills., 2,250.

W

- Wagon, boiler, Watts, ills., 2,024.
  - top, locomotive boiler, cons., 2,046.
- Ward drop Field tube boiler, ills., 2,072.
- Waste heat vertical boiler, Phoenix-Manning, ills., 2,103.
- Water, *back*, Clyde shell boiler, removable, ills., 2,051.
    - steam heating boiler, gilt edge, ills., 2,139.
  - boiler, circulation, ills., 1,803.
  - boiling, 1,792, 1,799 1,800–1,802
  - circulation in boilers, experiment, ills., 1,807.
  - contraction and expansion, 1,788.
  - drum, Vogt, ills., 2,251.
  - equivalent, calorimeter, 1,914.
  - *evaporation*, determining heating value of fuel, 1,861.
    - evaporation, fuels, table, 1,844.
  - feed, heating, saving, 1,807.
  - fire, tubes, diff., 2,023.
  - freezing, volumetric change, 1,785.
  - grate, water tube boiler, ills., 2,079.
  - height, steam boiler, diag., 1,980.
  - in wood, effect, 1,835.
  - level, upright shell boiler, proper, 2,044.
  - maximum density, 1,788.
  - pockets, shell boiler, Petrie's, ills., 2,039.
  - relative volume to ice, 1,785.
  - space, steam boiler, arrangement, 1,978.
- Water, steam boiler, amount in, 1,980.
  - tube boiler, see Boilers, *water tube*
- Watts wagon boiler, ills., 2,024.
- Webber vertical return fire tube boiler, ills., 2,107.
- Weighing beam, testing Riehle, ills., 2,009.
- Weight(s), analysis of air, 1,845.
  - balance, Eimer & Amend, ills., 1,894.
- Weisnegg's muffle furnace, ills., 1,898.
- Weld iron, steam boiler material, def., 1,994.
- Weldable, def., 1,996.
- Western, river shell boiler, ills., 2,030.
  - state size of bituminous coal, 1,831.
- Wet, steam, des., 1,789.
- White, cast iron, def., 1,994.
  - pig iron, def., 1,994.

Wicks Boiler Co., table of riveted joints, 2,188.
    non-sectional vertical water tube boiler, ills., 2,081.
Williamson underfeed steam heating boiler, ills., 2,137.
Wood, classes, 1,834, 1,835.
    coal, heating values, comparative, 1,835.
    combustion, air required for, 1,861.
    water, heat units, loss due to, 1,835.
Wrought iron, def., 1,988. process, 1,988.
    steam boiler materials, def., 1,994.

Y

Yarrow under discharge marine boiler, ills., 2,249.
Yield point, testing steam boiler materials, 2,013.

Z

Zero, absolute, determining, ills., 1,765.

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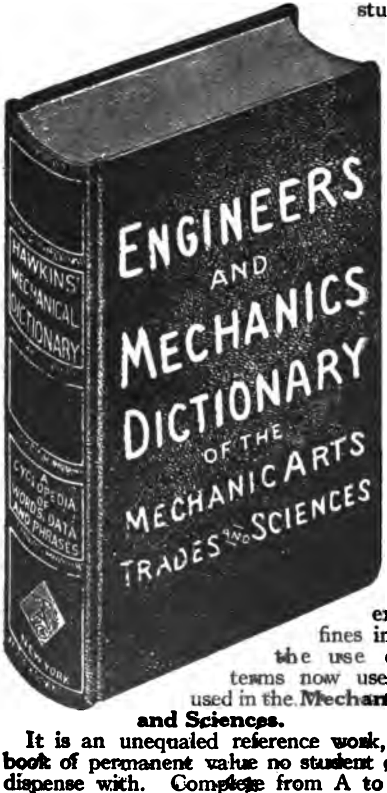
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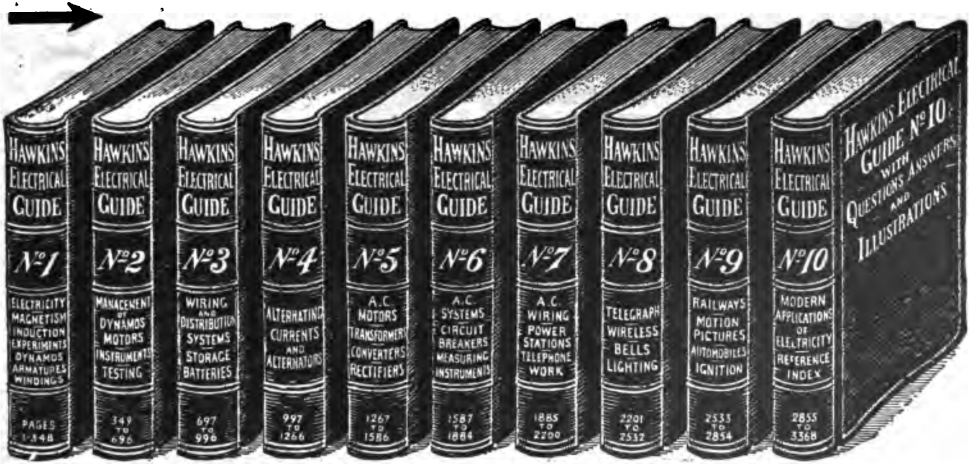
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